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Hironishi et al.

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(45) **Date of Patent: Oct. 6, 2015**

(54) **FREQUENCY MODULATION SIGNAL DEMODULATOR AND LIGHT RECEIVING APPARATUS**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

H04B 10/00 (2013.01)
H04B 10/67 (2013.01)
H04B 10/077 (2013.01)
H04L 27/148 (2006.01)

(52) **U.S. Cl.**

CPC ***H04B 10/676*** (2013.01); ***H04B 10/0775*** (2013.01); ***H04L 27/148*** (2013.01)

(58) **Field of Classification Search**

CPC H04B 10/548; H04B 10/556; H04B 10/5563; H04B 10/66; H04B 10/675; H04B 10/676; H04B 10/677

See application file for complete search history.

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* cited by examiner

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(74) *Attorney, Agent, or Firm* — Staas & Halsey LLP

(57) **ABSTRACT**

A frequency modulation signal demodulator includes: an optical signal that has a wavelength, a frequency modulation signal being superimposed onto the optical signal; an optical filter that inputs the optical signal and has a central wavelength of a pass band at a wavelength that is shifted from a central wavelength of a spectrum of the optical signal and that is set to allow the pass band to be located at one portion of the spectrum; and an asymmetry optical interferometer that demodulates the frequency modulation signal by splitting light which has passed through the optical filter, delaying different time between split lights, and interfering the split lights.

7 Claims, 20 Drawing Sheets

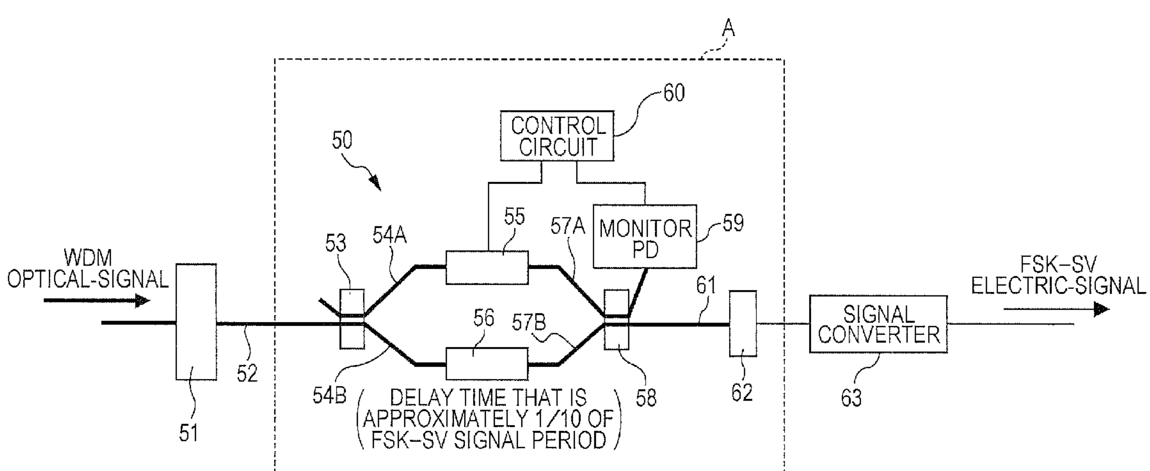


FIG. 1

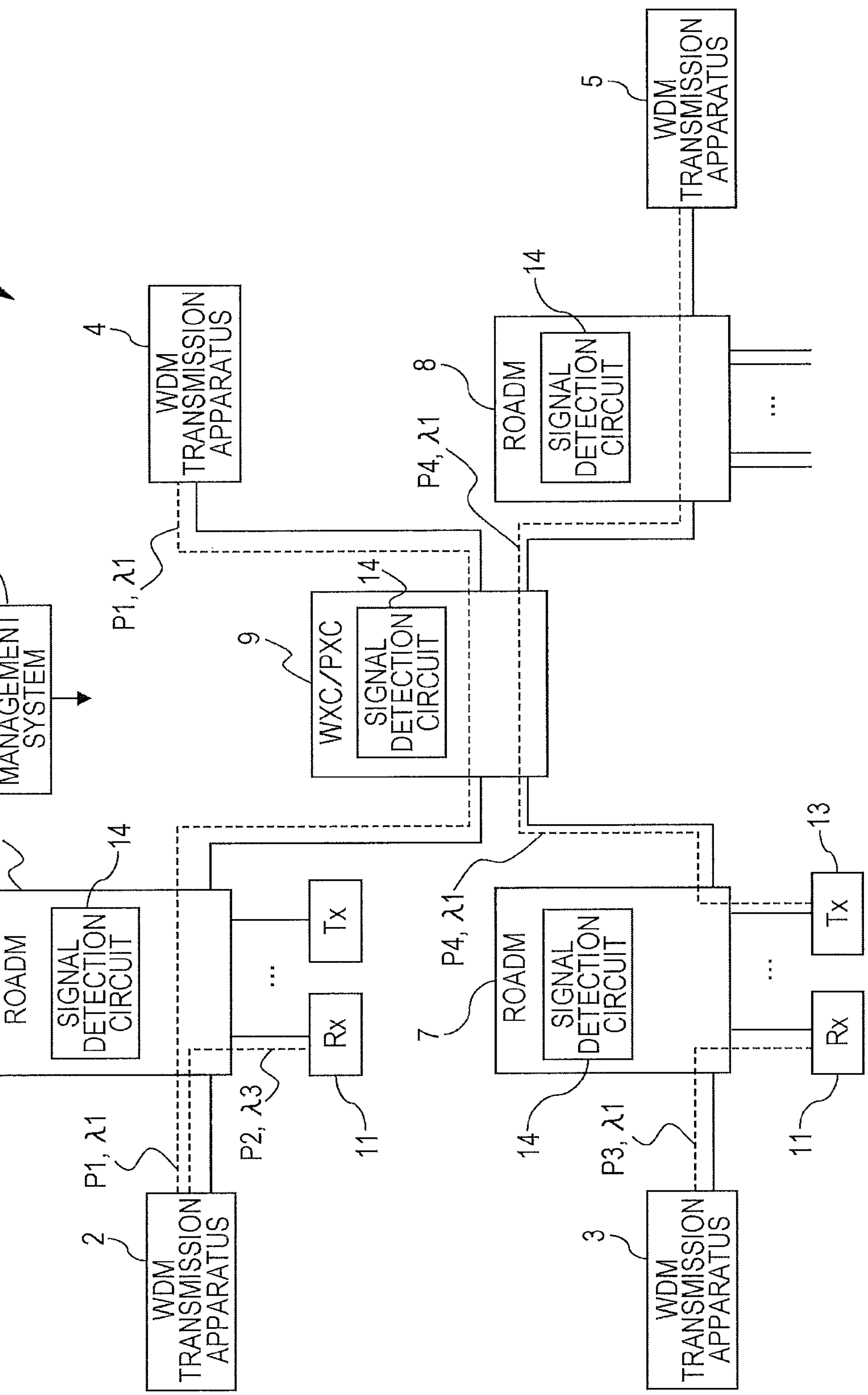
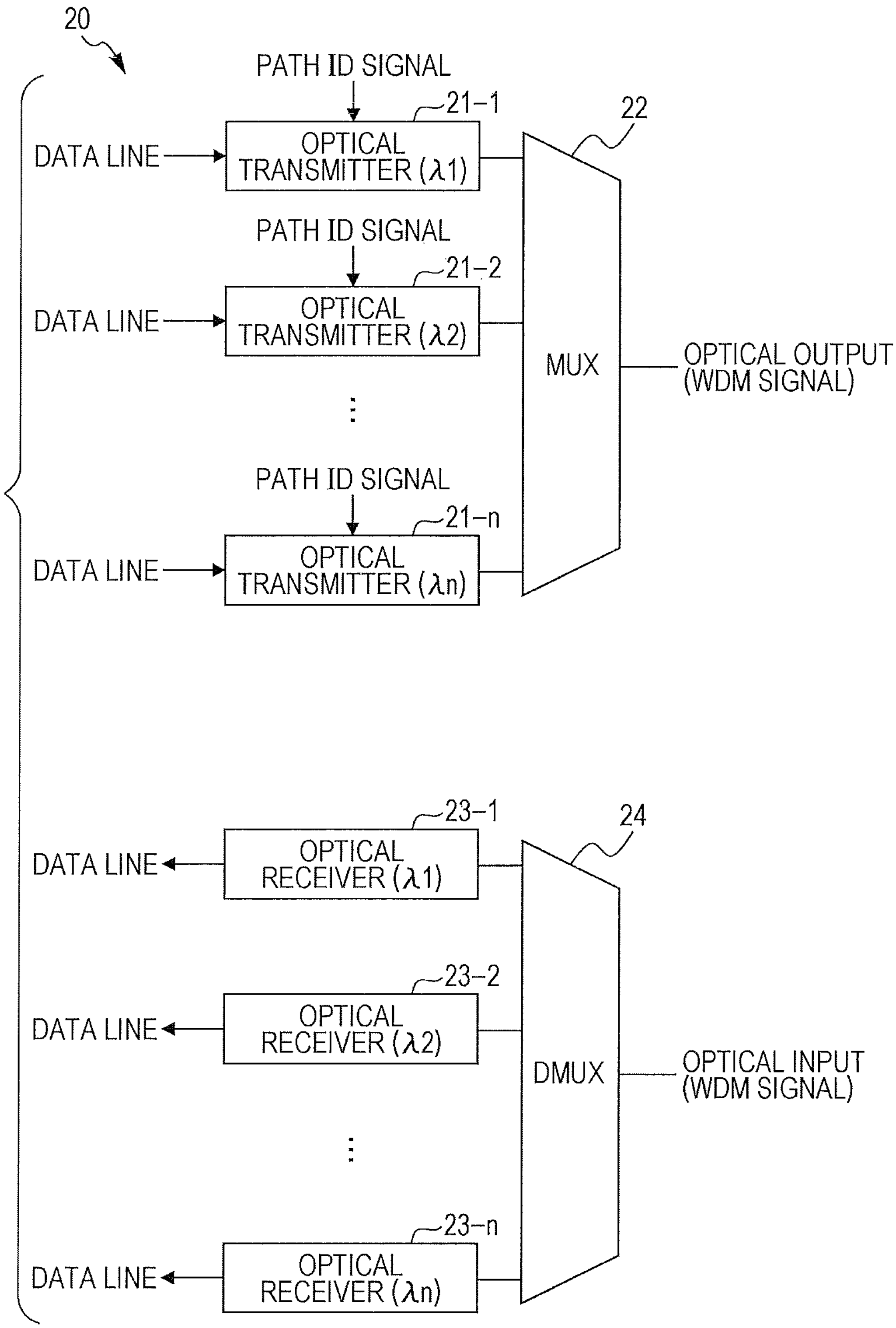

1
NETWORK MANAGEMENT SYSTEM
10
WDM TRANSMISSION APPARATUS
4
P1, λ1
WDM TRANSMISSION APPARATUS
5
WXC/PXC
SIGNAL DETECTION CIRCUIT
9
14
ROADM
SIGNAL DETECTION CIRCUIT
8
14
P4, λ1
ROADM
SIGNAL DETECTION CIRCUIT
6
14
Tx
Rx
P2, λ3
11
P1, λ1
WDM TRANSMISSION APPARATUS
2
ROADM
SIGNAL DETECTION CIRCUIT
7
14
P4, λ1
Tx
13
Rx
11
P3, λ1
WDM TRANSMISSION APPARATUS
3

FIG. 2



20
PATH ID SIGNAL
21-1
22
DATA LINE
OPTICAL TRANSMITTER (λ1)
PATH ID SIGNAL
21-2
DATA LINE
OPTICAL TRANSMITTER (λ2)
MUX
OPTICAL OUTPUT (WDM SIGNAL)
PATH ID SIGNAL
21-n
DATA LINE
OPTICAL TRANSMITTER (λn)
23-1
24
DATA LINE
OPTICAL RECEIVER (λ1)
23-2
DATA LINE
OPTICAL RECEIVER (λ2)
DMUX
OPTICAL INPUT (WDM SIGNAL)
23-n
DATA LINE
OPTICAL RECEIVER (λn)

FIG. 3A

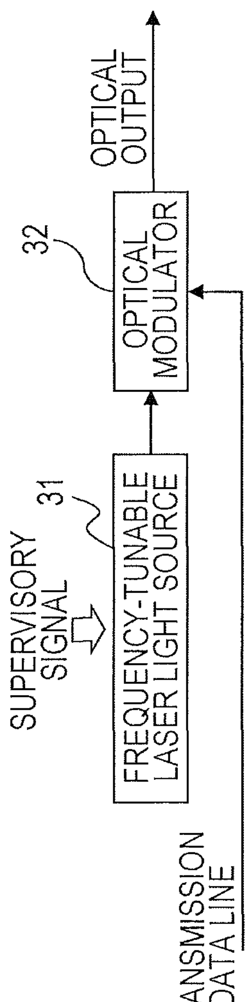

SUPERVISORY SIGNAL
31
FREQUENCY-TUNABLE LASER LIGHT SOURCE
32
OPTICAL MODULATOR
OPTICAL OUTPUT
TRANSMISSION DATA LINE

FIG. 3B

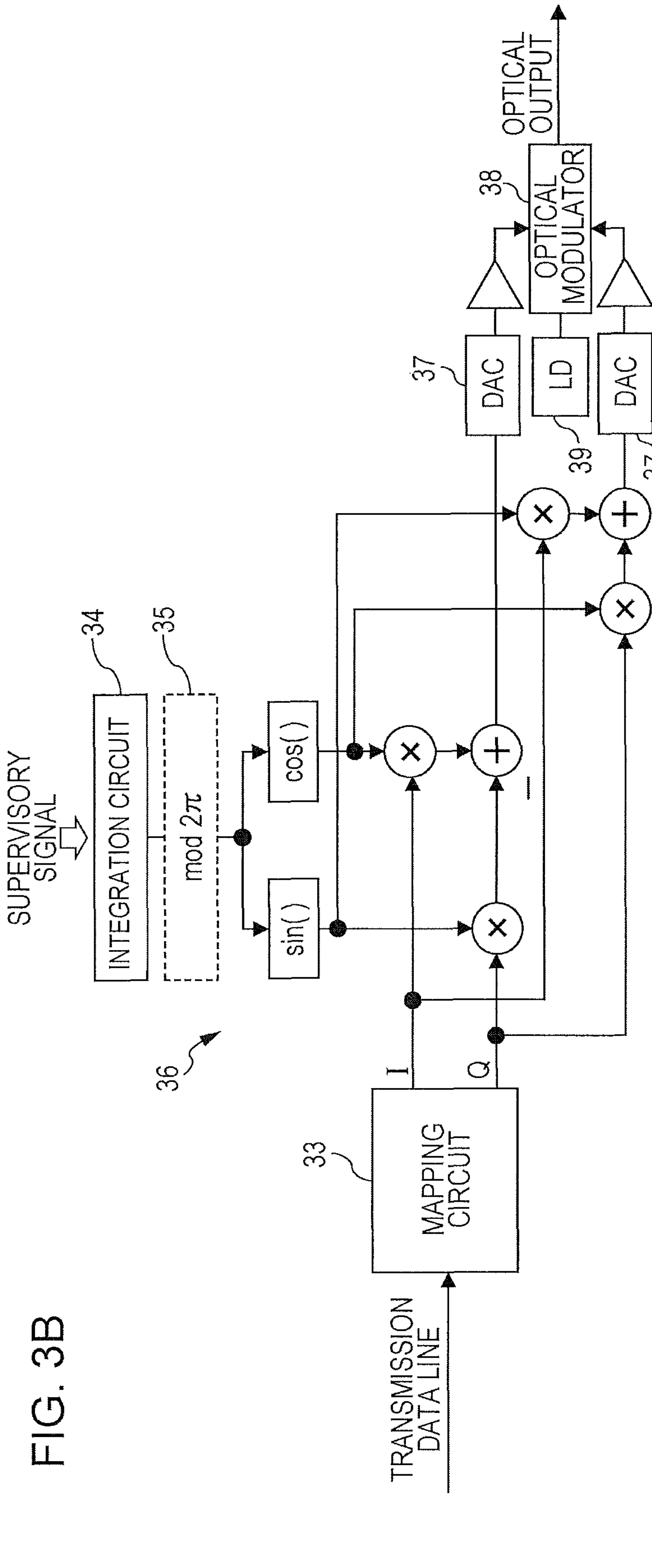

SUPERVISORY SIGNAL
34
INTEGRATION CIRCUIT
35
mod 2π
sin( )
cos( )
36
33
MAPPING CIRCUIT
I
Q
TRANSMISSION DATA LINE
37
DAC
39
LD
37
DAC
38
OPTICAL MODULATOR
OPTICAL OUTPUT

FIG. 4

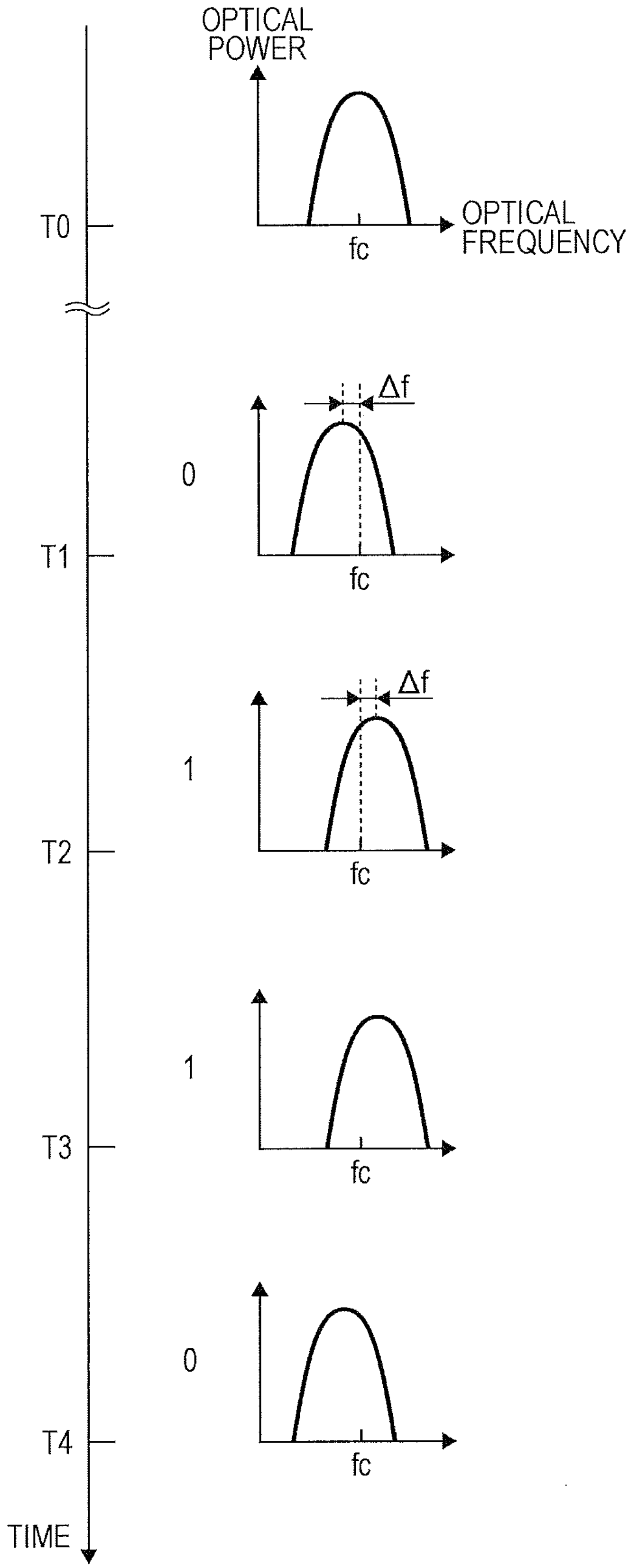

OPTICAL
POWER
OPTICAL
FREQUENCY
T0
fc
Δf
0
T1
fc
Δf
1
T2
fc
1
T3
fc
0
T4
fc
TIME

FIG. 5A

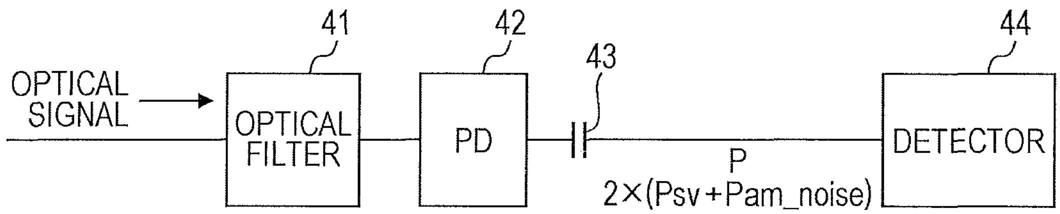

41
42
43
44
OPTICAL SIGNAL
OPTICAL FILTER
PD
DETECTOR
P
2×(Psv+Pam_noise)

FIG. 5B

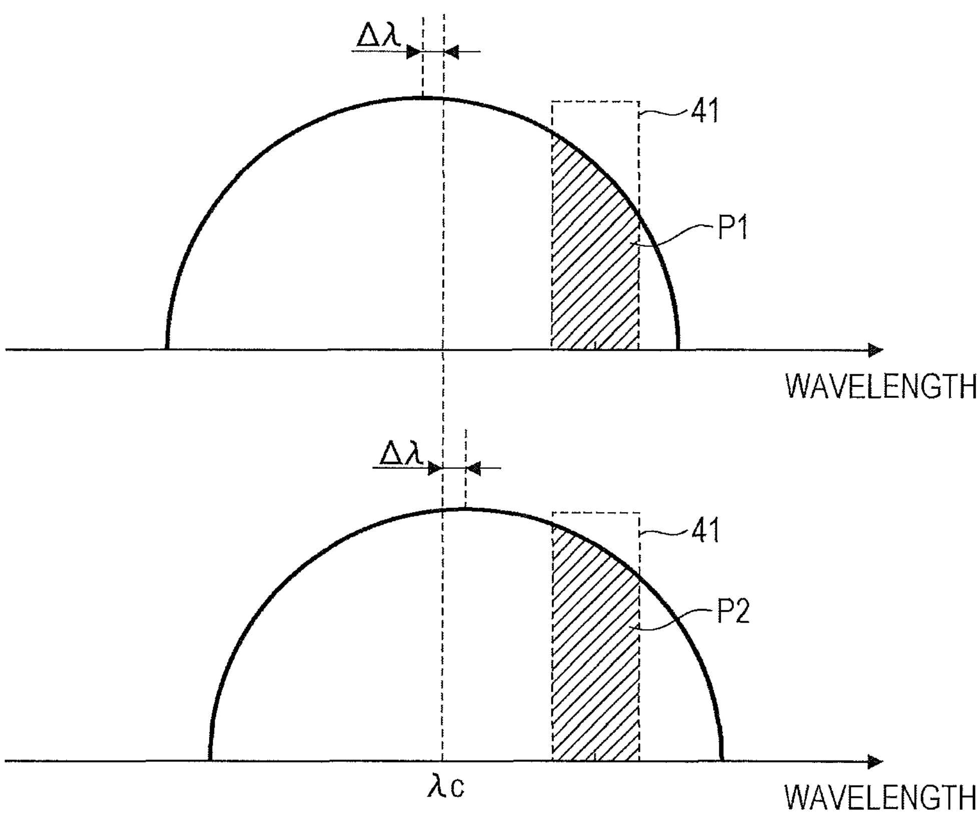

Δλ
41
P1
WAVELENGTH
Δλ
41
P2
λc
WAVELENGTH

FIG. 6

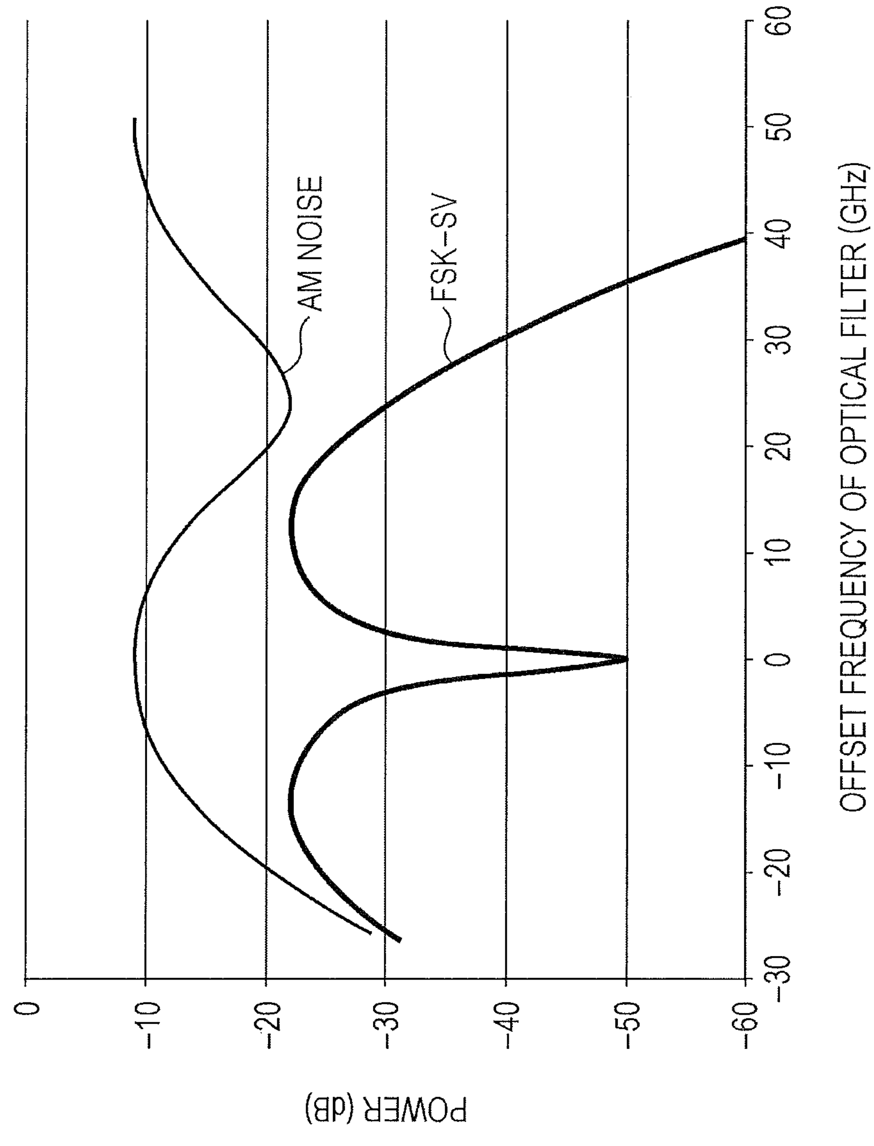

AM NOISE
FSK–SV
POWER (dB)
0
–10
–20
–30
–40
–50
–60
OFFSET FREQUENCY OF OPTICAL FILTER (GHz)
–30
–20
–10
0
10
20
30
40
50
60

FIG. 7

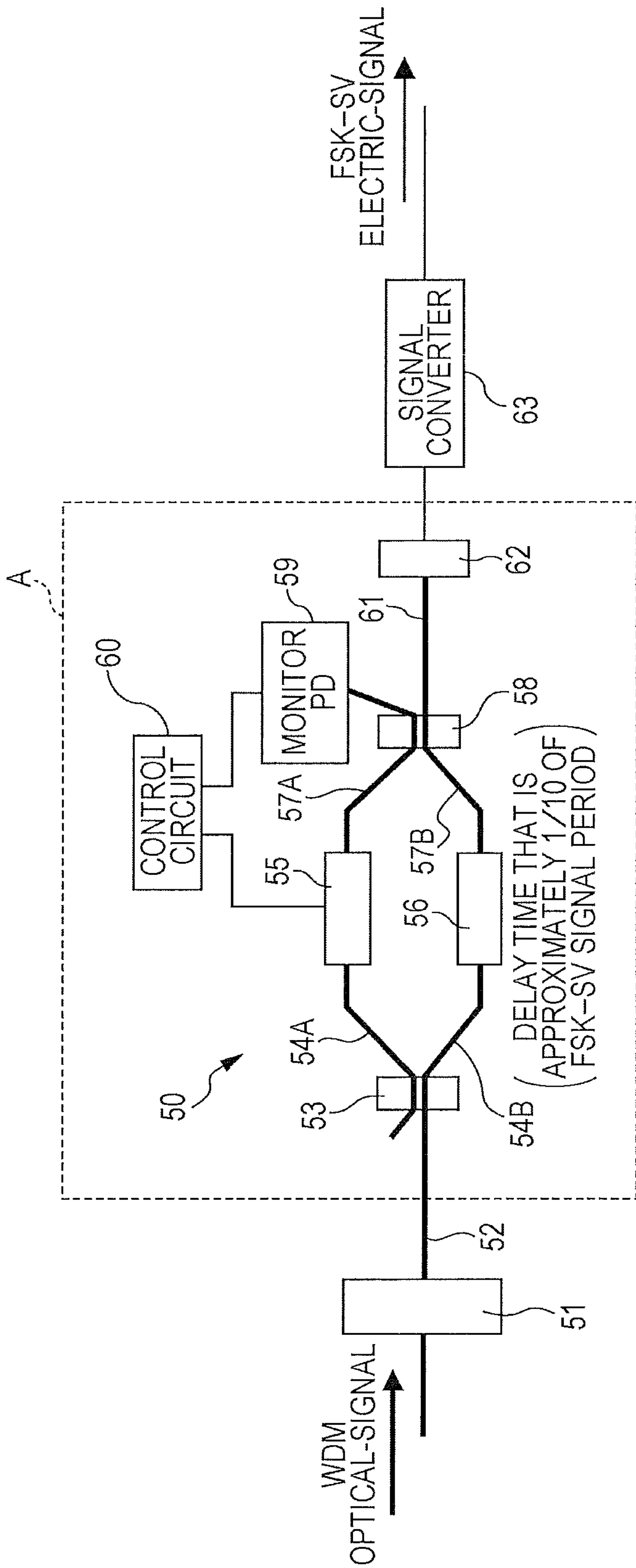

FSK–SV
ELECTRIC-SIGNAL
SIGNAL
CONVERTER
63
62
61
A
59
MONITOR
PD
58
60
CONTROL
CIRCUIT
57A
57B
55
56
50
54A
53
54B
52
51
DELAY TIME THAT IS
APPROXIMATELY 1/10 OF
FSK–SV SIGNAL PERIOD
WDM
OPTICAL-SIGNAL

FIG. 8

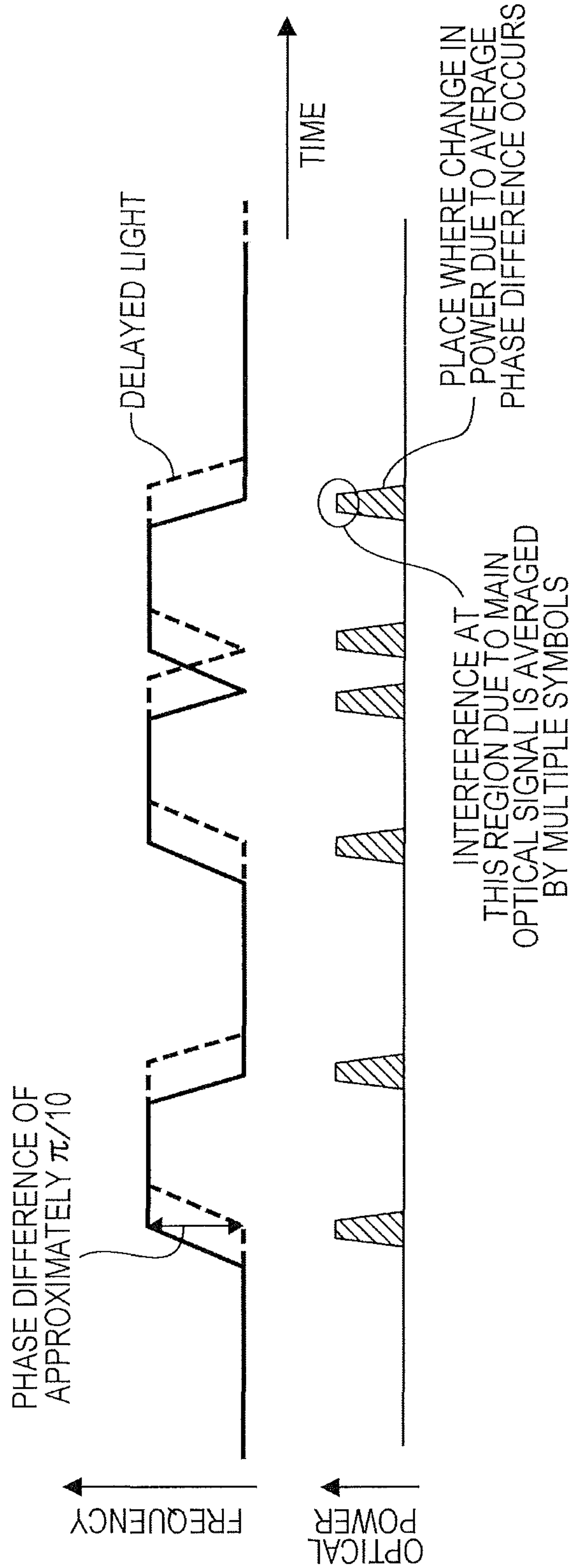

TIME
DELAYED LIGHT
PLACE WHERE CHANGE IN POWER DUE TO AVERAGE PHASE DIFFERENCE OCCURS
INTERFERENCE AT THIS REGION DUE TO MAIN OPTICAL SIGNAL IS AVERAGED BY MULTIPLE SYMBOLS
PHASE DIFFERENCE OF APPROXIMATELY $\pi/10$
FREQUENCY
OPTICAL POWER

FIG. 9

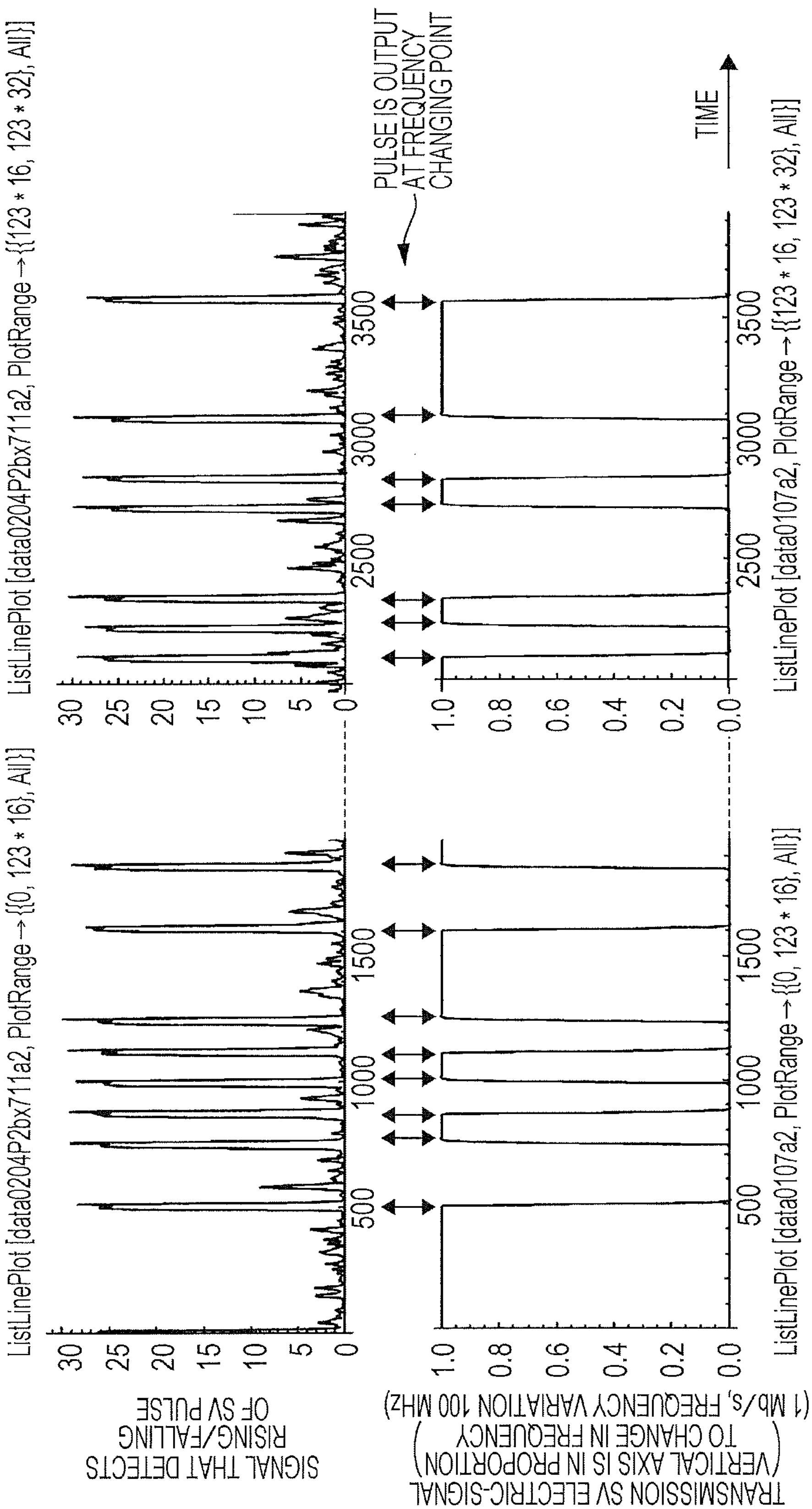
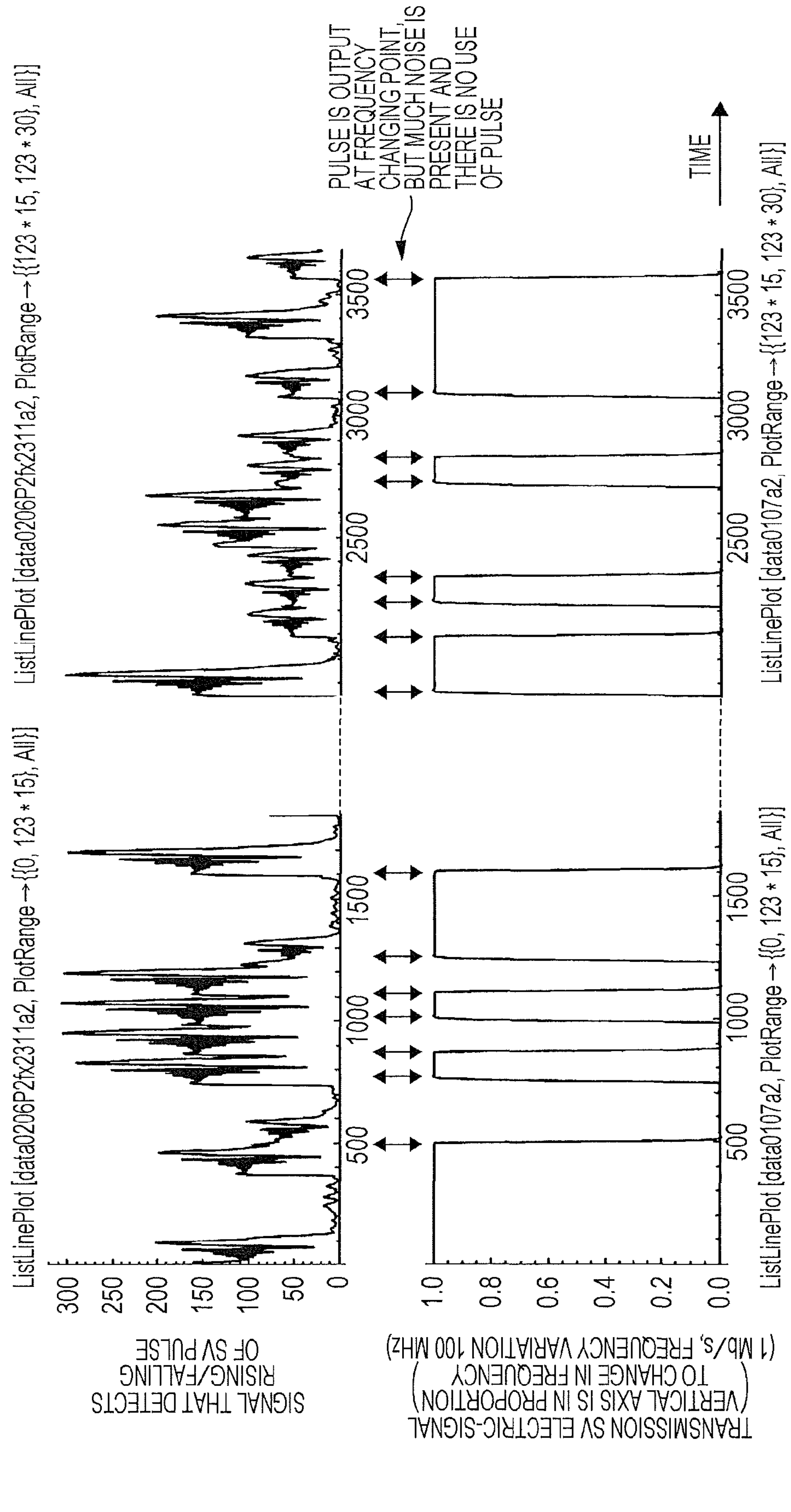

ListLinePlot [data0204P2bx711a2, PlotRange→{{0, 123 * 16}, All}]
ListLinePlot [data0204P2bx711a2, PlotRange→{{123 * 16, 123 * 32}, All}]
ListLinePlot [data0107a2, PlotRange→{{0, 123 * 16}, All}]
ListLinePlot [data0107a2, PlotRange→{{123 * 16, 123 * 32}, All}]
SIGNAL THAT DETECTS RISING/FALLING OF SV PULSE
TRANSMISSION SV ELECTRIC-SIGNAL (VERTICAL AXIS IS IN PROPORTION TO CHANGE IN FREQUENCY (1 Mb/s, FREQUENCY VARIATION 100 MHz)
PULSE IS OUTPUT AT FREQUENCY CHANGING POINT
TIME
30
25
20
15
10
5
0
1.0
0.8
0.6
0.4
0.2
0.0
500
1000
1500
2500
3000
3500

FIG. 10



ListLinePlot [data0206P2fx2311a2, PlotRange→{{0, 123 * 15}, All}]
ListLinePlot [data0206P2fx2311a2, PlotRange→{{123 * 15, 123 * 30}, All}]
SIGNAL THAT DETECTS RISING/FALLING OF SV PULSE
300
250
200
150
100
50
0
PULSE IS OUTPUT AT FREQUENCY CHANGING POINT, BUT MUCH NOISE IS PRESENT AND THERE IS NO USE OF PULSE
TRANSMISSION SV ELECTRIC-SIGNAL (VERTICAL AXIS IS IN PROPORTION TO CHANGE IN FREQUENCY) (1 Mb/s, FREQUENCY VARIATION 100 MHz)
1.0
0.8
0.6
0.4
0.2
0.0
500
1000
1500
2500
3000
3500
TIME
ListLinePlot [data0107a2, PlotRange→{{0, 123 * 15}, All}]
ListLinePlot [data0107a2, PlotRange→{{123 * 15, 123 * 30}, All}]

FIG. 11

```
ListLinePlot [10 * Log[(Abs[Flatten[ToExpression[
        Import["S126-130118/WF_MZLPF_0802_x8b2h4c2cF2B5AMex1a_Fa11.txt" , "Table" ]]]])^2 ] / Log[10.],
  PlotRange→{{0, 400}, All}]
```

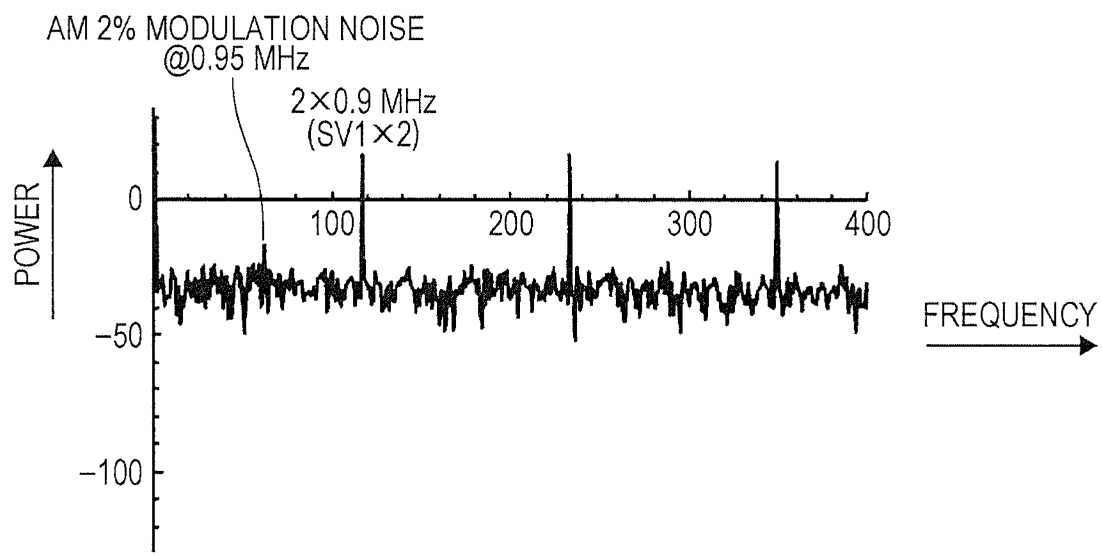


FIG. 12A

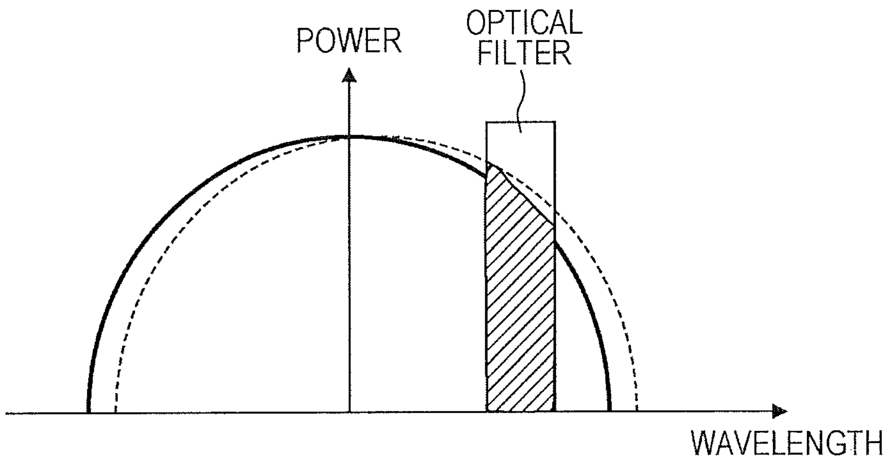


FIG. 12B

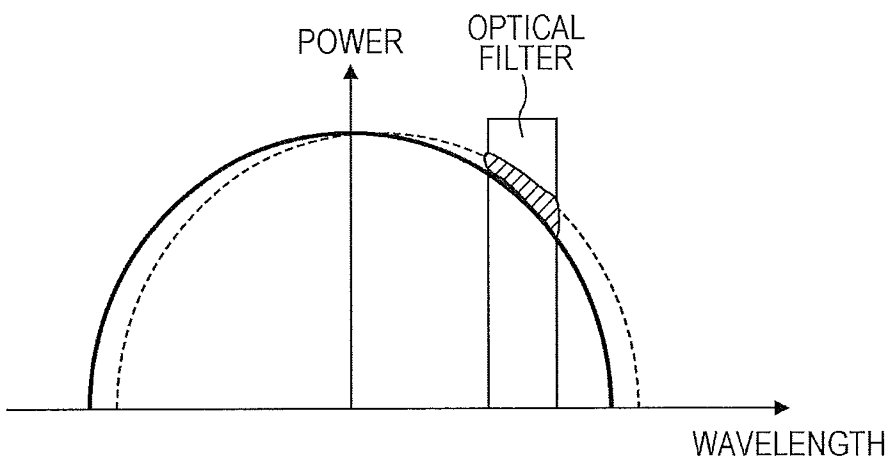


FIG. 13

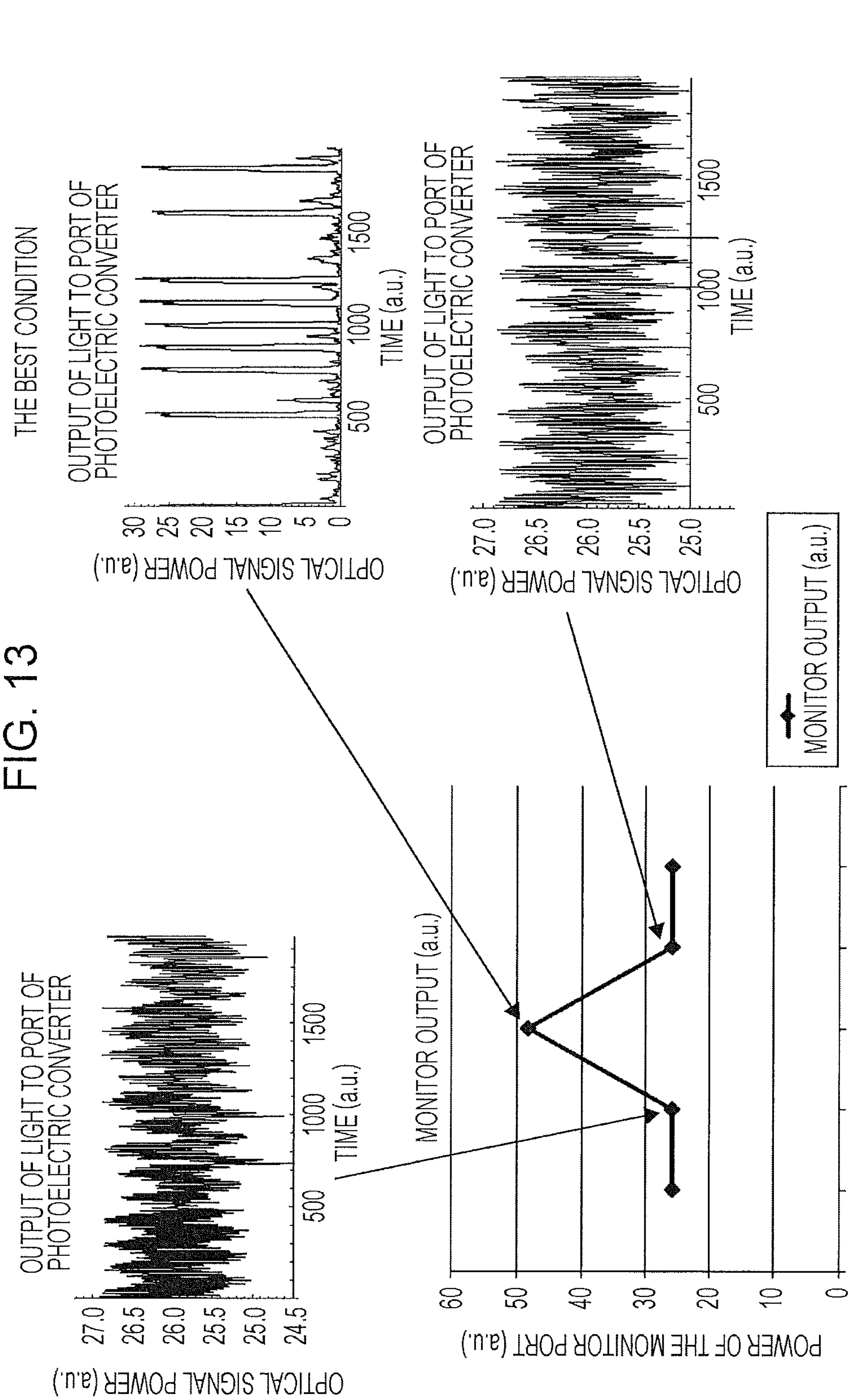

THE BEST CONDITION
OUTPUT OF LIGHT TO PORT OF PHOTOELECTRIC CONVERTER
OPTICAL SIGNAL POWER (a.u.)
TIME (a.u.)
OUTPUT OF LIGHT TO PORT OF PHOTOELECTRIC CONVERTER
OPTICAL SIGNAL POWER (a.u.)
TIME (a.u.)
OUTPUT OF LIGHT TO PORT OF PHOTOELECTRIC CONVERTER
OPTICAL SIGNAL POWER (a.u.)
TIME (a.u.)
MONITOR OUTPUT (a.u.)
POWER OF THE MONITOR PORT (a.u.)
DELAY TIME (ns)
MONITOR OUTPUT (a.u.)

FIG. 14

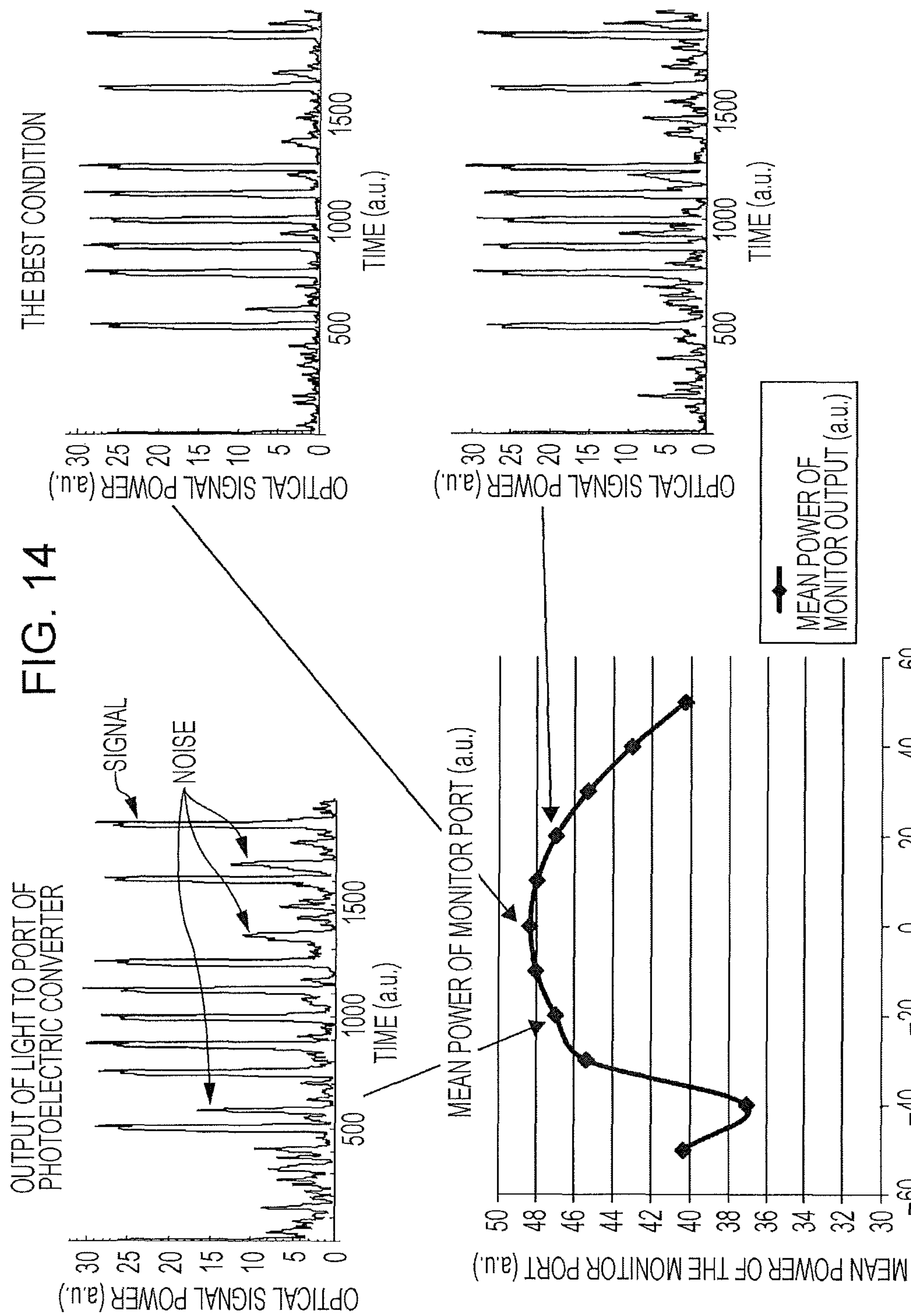
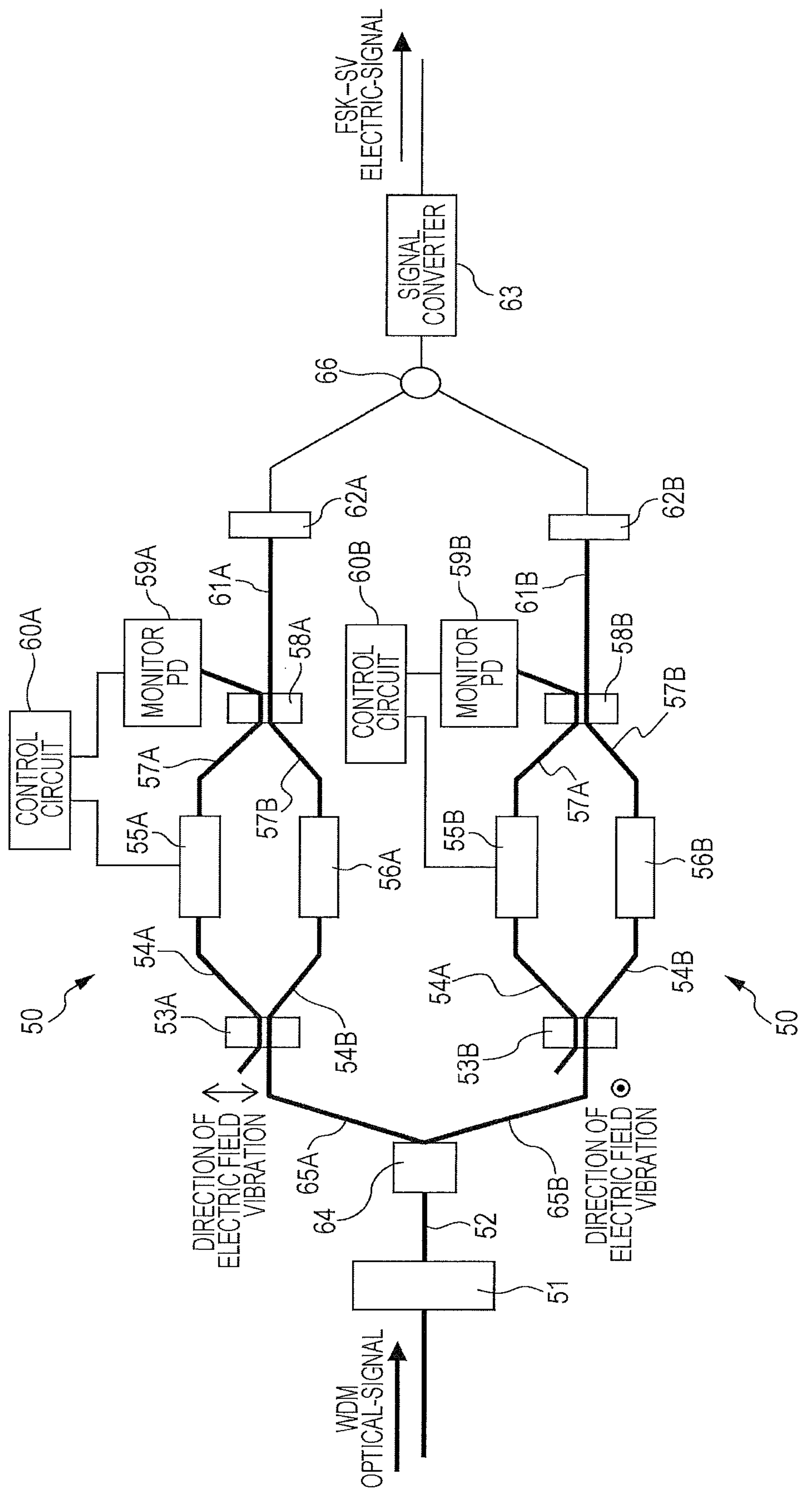

OUTPUT OF LIGHT TO PORT OF PHOTOELECTRIC CONVERTER
SIGNAL
NOISE
OPTICAL SIGNAL POWER (a.u.)
TIME (a.u.)
THE BEST CONDITION
MEAN POWER OF MONITOR PORT (a.u.)
MEAN POWER OF THE MONITOR PORT (a.u.)
PHASE DIFFERENCE (deg.)
MEAN POWER OF MONITOR OUTPUT (a.u.)

FIG. 15



FSK-SV
ELECTRIC-SIGNAL
SIGNAL
CONVERTER
63
66
62A
62B
CONTROL
CIRCUIT
60A
MONITOR
PD
59A
61A
58A
CONTROL
CIRCUIT
60B
MONITOR
PD
59B
61B
58B
57A
57B
57A
57B
55A
56A
55B
56B
54A
54B
54A
54B
50
53A
53B
50
DIRECTION OF
ELECTRIC FIELD
VIBRATION
65A
64
52
65B
DIRECTION OF
ELECTRIC FIELD
VIBRATION
51
WDM
OPTICAL-SIGNAL

FIG. 16

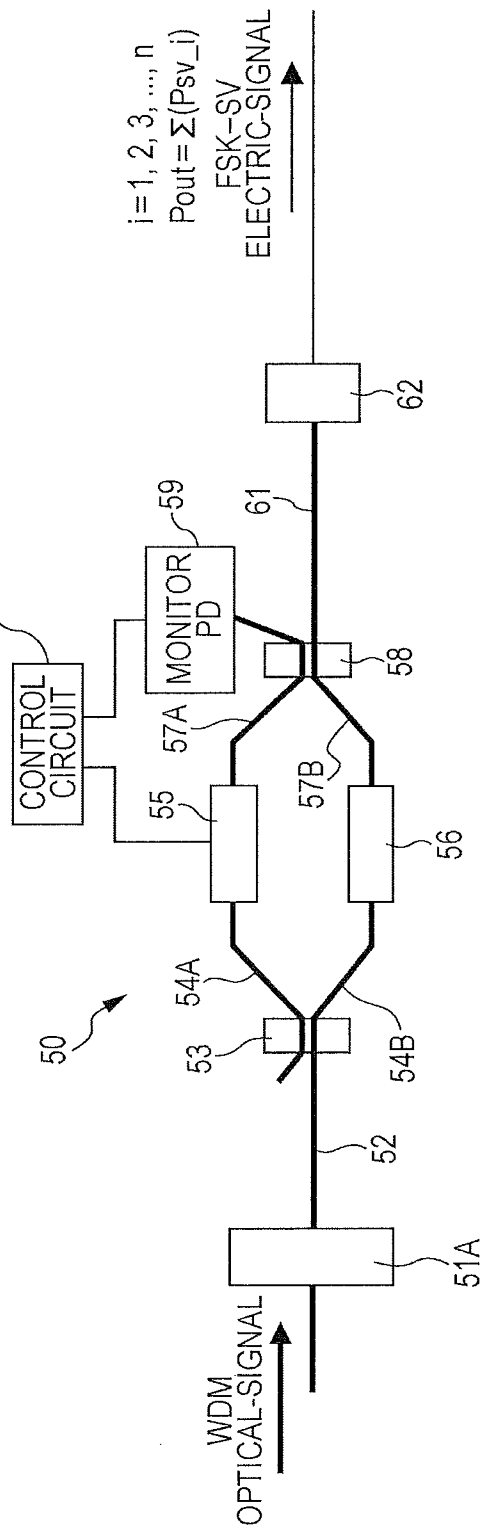

i=1, 2, 3, ..., n
Pout=Σ(Psv_i)
FSK-SV
ELECTRIC-SIGNAL
62
61
59
MONITOR PD
60
CONTROL CIRCUIT
58
57A
57B
55
56
54A
54B
53
50
52
51A
WDM
OPTICAL-SIGNAL

FIG. 17

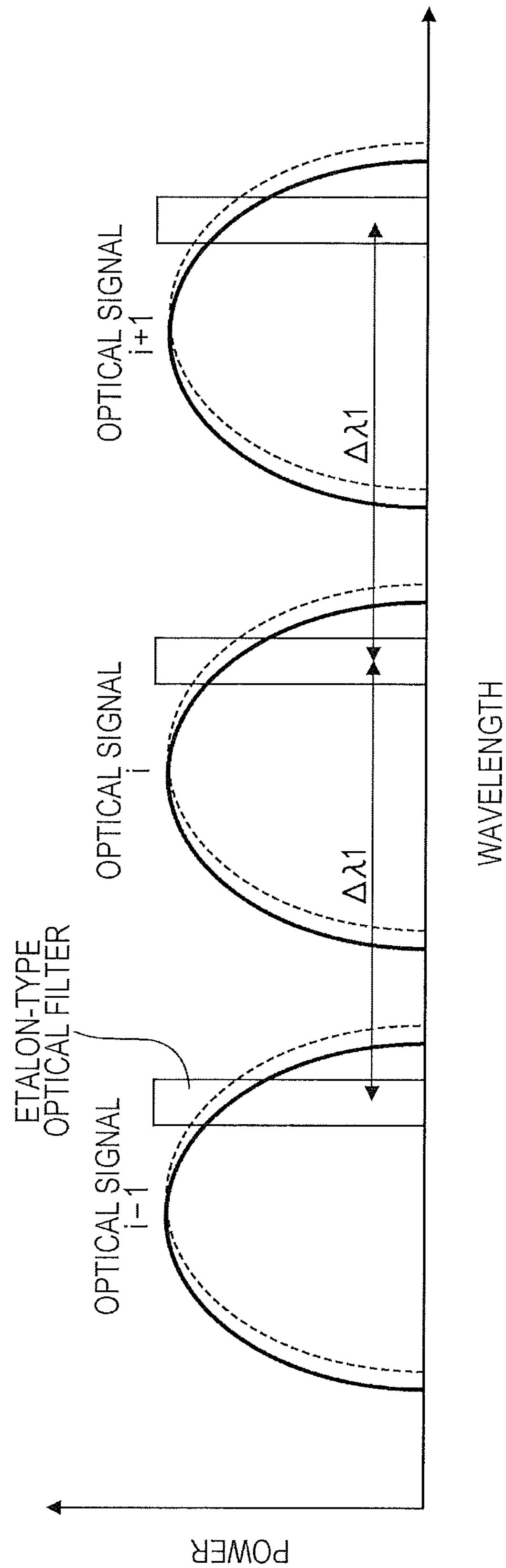

OPTICAL SIGNAL i+1
OPTICAL SIGNAL i
OPTICAL SIGNAL i−1
ETALON-TYPE OPTICAL FILTER
Δλ1
Δλ1
WAVELENGTH
POWER

FIG. 18

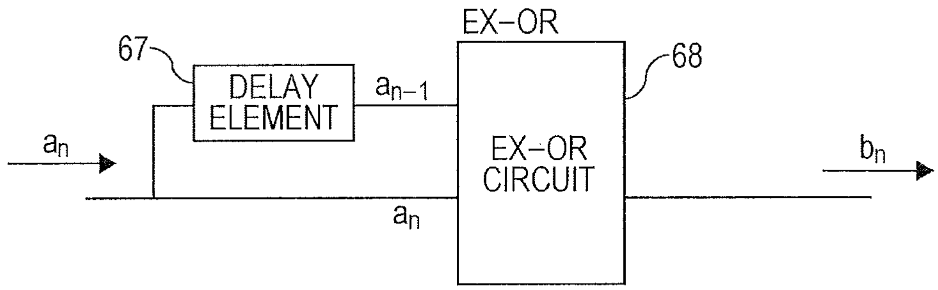


FIG. 19

a_{n-1}	a_n	b_n
1	0	1
0	1	1
1	1	0
0	0	0

FIG. 20

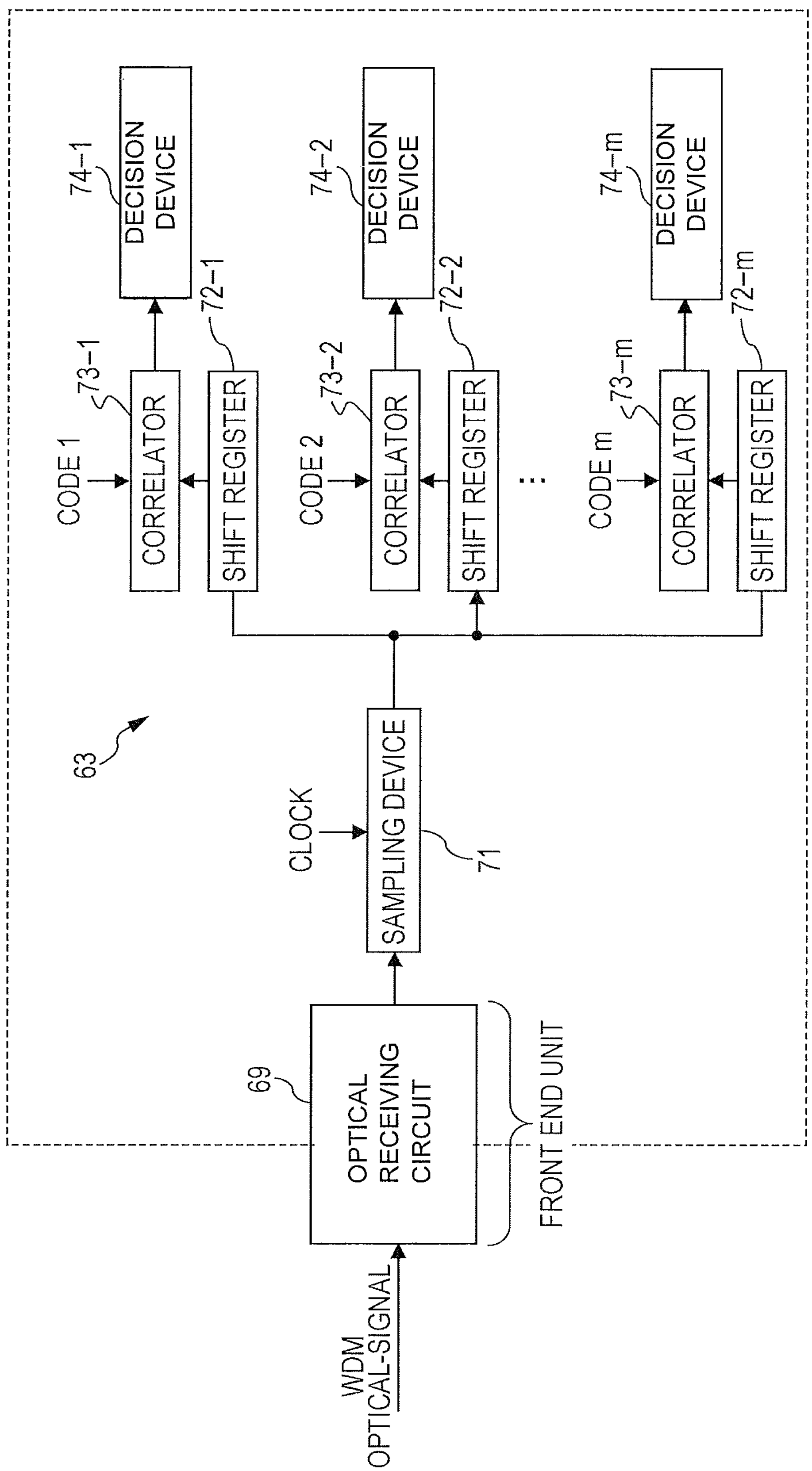
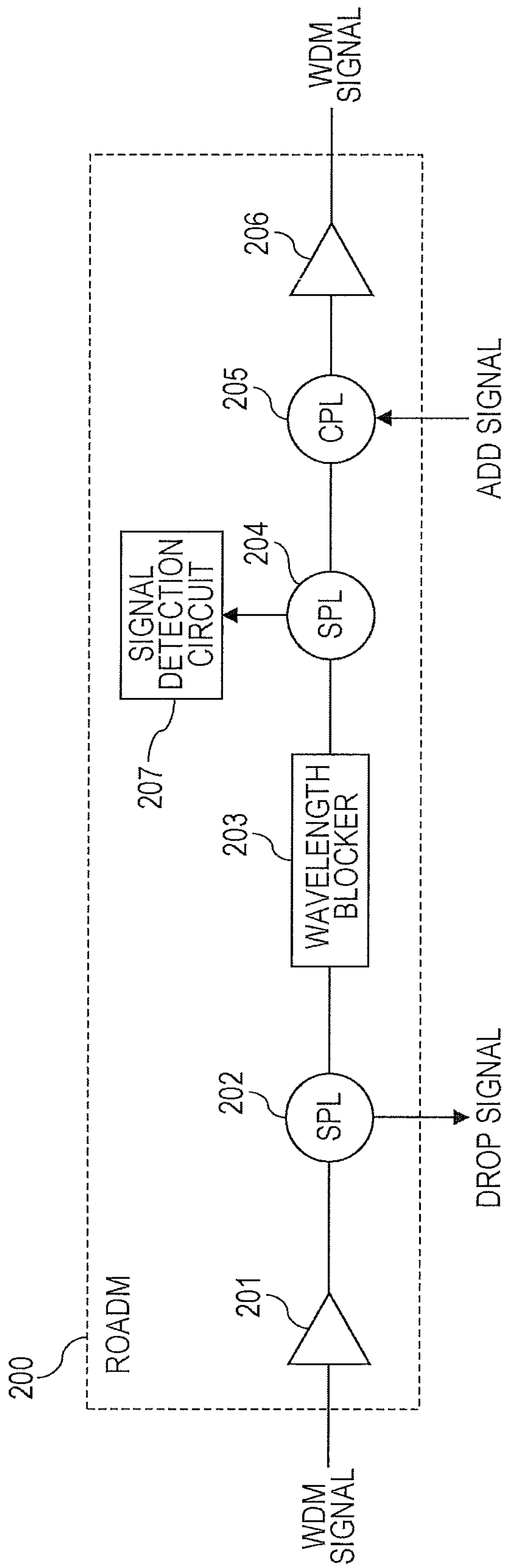

63
74–1
DECISION DEVICE
74–2
DECISION DEVICE
74–m
DECISION DEVICE
72–1
72–2
72–m
73–1
73–2
73–m
CODE 1
CORRELATOR
SHIFT REGISTER
CODE 2
CORRELATOR
SHIFT REGISTER
CODE m
CORRELATOR
SHIFT REGISTER
CLOCK
SAMPLING DEVICE
71
69
OPTICAL RECEIVING CIRCUIT
FRONT END UNIT
WDM OPTICAL-SIGNAL

FIG. 21


WDM SIGNAL
200
ROADM
201
202
SPL
DROP SIGNAL
203
WAVELENGTH BLOCKER
207
SIGNAL DETECTION CIRCUIT
204
SPL
205
CPL
ADD SIGNAL
206
WDM SIGNAL

FREQUENCY MODULATION SIGNAL DEMODULATOR AND LIGHT RECEIVING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2013-169202, filed on Aug. 16, 2013, the entire contents of which are incorporated herein by reference.

FIELD

The embodiments discussed herein are related to a frequency modulation signal demodulator and a light receiving apparatus.

BACKGROUND

In recent years, with the spread of reconfigurable optical add/drop multiplexers (ROADM), availability of a network connection has increased. For this reason, there is an increasing demand for a function that may observe a network connection status in a simple manner. As one example of a technology that meets such a demand, a technology has been known that superimposes a control signal such as a supervisory signal onto an optical signal that carries data.

For example, in a WDM transmission system, the control signal for identifying an optical path is superimposed onto the optical signal (a main optical signal) of each wavelength (channel), which is included in a WDM signal. In this case, the optical transmission apparatus (hereinafter referred to as a "node") or a receiver may recognize a transmission source of the optical signal and a path of the optical signal by demodulating the control signal from the received optical signal.

In such a light transmitting system, data on each channel is modulated, for example, in a multi-level modulation manner such as QPSK, mQAM (m is 16, 64, and 256) and thus is transmitted along an optical transmission path. On the other hand, the control signal such as the supervisory signal, for example, is superimposed on main signal light in a frequency shift keying (FSK) manner.

Moreover, although an object of the disclosure is different, International Publication Pamphlet No. WO 2010/026757 discusses that a transmission apparatus phase-modulates or frequency-modulates an optical signal, which is phase-modulated based on a first signal, based on a second signal that is slower in speed than the first signal, and thus transmits the phase- or frequency-modulated optical signal. Furthermore, a receiving apparatus disclosed in International Publication Pamphlet No. WO 2010/026757 splits the optical signal received from a transmitting apparatus, performs delaying interference on one split optical signal and thus outputs interference light. Then, the receiving apparatus converts the interference light into an electric signal, and thus obtains the second signal based on the full-wave rectified signal and obtains the first signal based on the other split signal. Accordingly, in the technology disclosed in International Publication Pamphlet No. WO 2010/026757, multiple signals that are different in speed may be multiplexed, and information may be multiplexed in the shape of a single peak spectrum in a single wavelength slot.

Furthermore, Japanese Laid-open Patent Publication No. 02-096719 discusses an optical signal demodulation circuit including an optical filter that allows a specific optical frequency for the optical signal that is frequency-modulated to an n value (n is an integer that is 2 or greater) to pass through and a light receiving element that receives light that passes through the optical filter. The optical filter disclosed in Japanese Laid-open Patent Publication No. 02-096719 is a Mach-Zehnder type periodic optical filter that outputs optical frequencies corresponding to the n values to different output ports.

If the control signal is superimposed onto the optical signal in a frequency shift keying manner, the receiver, for example, demodulates the control signal by converting a frequency modulation component of the optical signal into an amplitude component. However, in this case, when the frequency modulation component for superimposing the control signal onto the optical signal is large (that is, when a range of frequency change is wide), there is a concern that quality of data (for example, an error rate) that is carried by that optical signal will deteriorate. For this reason, it is preferable that the frequency modulation component for superimposing the control signal onto the optical signal be small enough for the quality of the data not to deteriorate.

When the frequency modulation component of the optical signal is small, the amplitude component that is obtained from the frequency modulation component is also small in the receiver. In such a case, the amplitude component that is obtained from the frequency modulation component of the optical signal is easily influenced by an intensity modulation noise (an AM noise) that occurs in a transmission path between the transmitter and the receiver and the like. Therefore, detection sensitivity of the control signal is decreased in the receiver.

Moreover, the detection sensitivity of the frequency modulation signal that is superimposed onto the optical signal is not disclosed in International Publication Pamphlet No. WO 2010/026757 and Japanese Laid-open Patent Publication No. 02-096719.

SUMMARY

According to an aspect of the embodiments, a frequency modulation signal demodulator includes: an optical signal that has a wavelength, a frequency modulation signal being superimposed onto the optical signal; an optical filter that inputs the optical signal and has a central wavelength of a pass band at a wavelength that is shifted from a central wavelength of a spectrum of the optical signal and that is set to allow the pass band to be located at one portion of the spectrum; and an asymmetry optical interferometer that demodulates the frequency modulation signal by splitting light which has passed through the optical filter, delaying different time between split lights, and interfering the split lights.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates an example of an optical transmission system;

FIG. **2** illustrates a configuration of WDM transmission equipment;

FIGS. **3**A and **3**B illustrate examples of an optical transmitter that has a function to superimpose a supervisory signal;

FIG. **4** is a view for illustrating frequency modulation;

FIGS. **5**A and **5**B are views for illustrating detection of frequency modulated signals;

FIG. **6** illustrates simulation results about the power of converted amplitude output of a FSK-SV signal and the power of AM noise;

FIG. **7** is a block diagram illustrating a configuration example of an asymmetry interferometer-type FSK-SV signal demodulator as a signal demodulation circuit according to one embodiment;

FIG. **8** is a diagram illustrating one example (on the upper portion) of a frequency change over time in each optical signal that is input into an optical combiner illustrated in FIG. **7** and one example (on the lower portion) of a change over time in output optical power of the optical combiner;

FIG. **9** is a diagram illustrating a waveform example (on the lower portion) of a transmission FSK-SV signal (an electric signal) and a waveform example (on the upper portion) of the electric signal that indicates a frequency changing point of the FSK-SV signal pulse described above;

FIG. **10** is a diagram that is equivalent to FIG. **9** when a BPF illustrated in FIG. **7** is not provided;

FIG. **11** is a diagram illustrating an output waveform example of a photoelectric converter that results when a pass band of the BPF illustrated in FIG. **7** is set to 20 GHz and an offset frequency is set to 10 GHz;

FIGS. **12**A and **12**B are conceptional diagrams, each illustrating an amount of light that may be used as an FSK-SV signal demodulator;

FIG. **13** is a diagram illustrating one example of average output optical power of a monitor port with respect to delay time in an optical interferometer for describing control by a control circuit illustrated in FIG. **7**;

FIG. **14** is a diagram illustrating one example of the average output optical power of the monitor port with respect to a phase difference in the optical interferometer for describing control by a control circuit illustrated in FIG. **7**;

FIG. **15** is a block diagram illustrating a configuration example of an asymmetry interferometer-type FSK-SV signal demodulator according to a first modification example;

FIG. **16** is a block diagram illustrating a configuration example of an asymmetry interferometer-type FSK-SV signal demodulator according to a second modification example;

FIG. **17** is a diagram for describing a periodic pass band of an etalon-type optical filter illustrated in FIG. **16**;

FIG. **18** is a block diagram illustrating a configuration example of a differential encoder according to the second modification example;

FIG. **19** is a diagram illustrating one example of a truth-value table of the differential encoder illustrated in FIG. **18**;

FIG. **20** is a block diagram illustrating a configuration example of a signal converter according to the second modification example; and

FIG. **21** illustrates one example of an optical transmission apparatus that includes a circuit (a signal demodulator) which demodulates the FSK-SV signal.

DESCRIPTION OF EMBODIMENTS

Hereinafter, embodiments of the present disclosure are described below referring to the drawings. However, the embodiments that are described below are only examples, and this is not intended to exclude modifications or applications of the technology that are not specified below. Moreover, in the drawings that are referred to when describing the embodiments below, portions that are given the same reference numeral are the same or similar, except as otherwise specified.

FIG. **1** illustrates an example of an optical transmission system in which a signal detection circuit according to embodiments of the present invention is used. An optical transmission system **1** illustrated in FIG. **1** includes WDM transmission equipment **2-5**, reconfigurable optical add/drop multiplexers (ROADMs) **6-8**, a wavelength cross connect (WXC) (or photonic cross connect (PXC)) **9**, and a network management system (NMS) **10**.

The WDM transmission equipment **2**, **3** and **5** are connected to the reconfigurable optical add/drop multiplexers **6**, **7** and **8** via the optical fiber links, respectively. The reconfigurable optical add/drop multiplexers **6**, **7** and **8** are connected to the wavelength cross connect **9** via optical fiber links, respectively. The WDM transmission equipment **4** is connected to the wavelength cross connect **9** via an optical fiber link. Note that one or more optical amplifiers may be provided on each of the optical fiber links.

Each of the WDM transmission equipment **2-5** transmits and receives a WDM optical signal including a plurality of optical signals having different wavelengths. Each of the reconfigurable optical add/drop multiplexers **6-8** may transmit an optical signal of a specified wavelength channel among the received WDM optical signal. Further, each of the reconfigurable optical add/drop multiplexers **6-8** may branch an optical signal having a specified wavelength among the received WDM optical signal and guides the branched optical signal to a client circuit. Further, each of the reconfigurable optical add/drop multiplexers **6-8** may insert, into a WDM optical signal, an optical signal inputted from a client circuit. The wavelength cross connect **9** includes a plurality of input ports and a plurality of output ports, and guides an input signal to an output port so as to realize a specified optical path. Note that, although not clearly indicated, the wavelength cross connect **9** may have a function of branching an optical signal to a client circuit, and a function of inserting an optical signal into a WDM optical signal similarly to the reconfigurable optical add/drop multiplexers **6-8**.

In the optical transmission system **1**, the network management system **10** provides an optical path designated by a user. That is, the network management system **10** controls the WDM transmission equipment **2-5**, the reconfigurable optical add/drop multiplexers **6-8**, and the wavelength cross connect **9** so as to realize the optical path designated by the user.

In the example illustrated in FIG. **1**, optical paths P**1** to P**4** are provided in the optical transmission system **1**. Each of the optical paths is represented by a broken line. The optical path P**1** transmits an optical signal from the WDM transmission equipment **2** to the WDM transmission equipment **4** via the reconfigurable optical add/drop multiplexer **6** and the wavelength cross connect **9**. The optical path P**2** transmits an optical signal from the WDM transmission equipment **2** to a client **11** via the reconfigurable optical add/drop multiplexer **6**. The optical path P**3** transmits an optical signal from the WDM transmission equipment **3** to a client **12** via the reconfigurable optical add/drop multiplexer **7**. The optical path P**4** transmits an optical signal from a client **13** to the WDM transmission equipment **5** via the reconfigurable optical add/drop multiplexer **7**, the wavelength cross connect **9**, and the reconfigurable optical add/drop multiplexer **8**. Note that each of the optical paths P**1** to P**4** may bi-directionally transmit optical signals.

In the optical transmission system **1** configured as described above, the network management system **10** may assign a same wavelength to different optical paths in order to efficiently or flexibly use communication resources. In the example illustrated in FIG. **1**, wavelengths λ**1**, λ**3**, λ**1** and λ**1** are assigned to the optical paths P**1**, P**2**, P**3** and P**4**, respectively.

A user or a network administrator sometimes wants to check whether or not the optical paths are correctly implemented. However, when the same wavelength is assigned to a plurality of optical paths, it is difficult to identify each of the optical paths only by monitoring the spectrum of each of the wavelength channels. For example, in the wavelength cross connect **9**, it is difficult to identify the optical paths P**1** and P**4** only by monitoring the spectrum of each of the wavelength channels.

Thus, the network management system **10** assigns a path ID to each of the optical paths. By so doing, a transmission source apparatus of an optical path superimposes a supervisory signal representing a path ID on an optical signal to be transmitted via the optical path. For example, the WDM transmission equipment **2** superimposes a supervisory (SV) signal representing "path ID=1" on an optical signal to be transmitted via the optical path P**1**, and superimposes a supervisory signal representing "path ID=2" on an optical signal to be transmitted via the optical path P**2**. In this example, the supervisory signal is superimposed on the optical signal by frequency modulation.

Optical transmission equipment includes a signal detection circuit **14** that detects a supervisory signal superimposed on an optical signal and acquires a path ID from the supervisory signal. In the example illustrated in FIG. **1**, the optical transmission equipment corresponds to the reconfigurable optical add/drop multiplexers **6**-**8** and the wavelength cross connect **9**. However, the signal detection circuit **14** need not necessarily be provided at all of the optical transmission equipment, and a plurality of the signal detection circuits **14** may be provided at one optical transmission equipment. Also, the signal detection circuit **14** may be implemented within the optical transmission equipment or may be configured to be connected to the optical transmission equipment. Further, the signal detection circuit **14** may be provided at the WDM transmission equipment **2**-**5**.

FIG. **2** illustrates a configuration of WDM transmission equipment. In the example illustrated in FIG. **1**, WDM transmission equipment **20** illustrated in FIG. **2** corresponds to the WDM transmission equipment **2**-**5**. The WDM transmission equipment **20** includes optical transmitters **21**-**1** to **21**-*n*, a multiplexer **22**, optical receivers **23**-**1** to **23**-*n*, and a demultiplexer **24**.

Each of the optical transmitters **21**-**1** to **21**-*n* generates an optical signal by modulating carrier light with an input data stream. The wavelengths λ**1** to λn of the carrier light respectively used by the optical transmitters **21**-**1** to **21**-*n* are different from each other (that is, different optical frequencies). The network management system **10** assigns path IDs to each of the optical transmitters **21**-**1** to **21**-*n*. The path ID is given as a supervisory signal to each of the optical transmitters **21**-**1** to **21**-*n*. The supervisory signal is, for example, a code having a specified length. In this case, the codes for identifying the respective optical paths are orthogonal to each other when the optical transmitters **21**-**1** to **21**-*n* are used with a detector illustrated in FIG. **10**. Further, the supervisory signals may be tone signals having mutually different frequencies. The tone signal is not limited in particular and is, for example, a sine wave signal. Note that the rate (the bit rate of the code, the frequency of the tone signal, and the like) of the supervisory signal is sufficiently low as compared with the rate of the data string.

Each of the optical transmitters **21**-**1** to **21**-*n* can superimpose a supervisory signal on an optical signal by frequency modulation. That is, each of the optical transmitters **21**-**1** to **21**-*n* can output an optical signal with a supervisory signal superimposed by frequency modulation. Further, the multiplexer **22** multiplexes the optical signals outputted from the optical transmitters **21**-**1** to **21**-*n* to generate a WDM optical signal.

Note that the modulation schemes respectively used by the optical transmitters **21**-**1** to **21**-*n* for modulating main signal data streams may not be the same as one another. For example, the WDM transmission equipment may be configured such that the optical transmitter **21**-**1** transmits a QPSK modulated optical signal, and the optical transmitter **21**-**2** transmits a 16QAM modulated optical signal. Further, the symbol rate or the bit rate of optical signals respectively outputted from the optical transmitters **21**-**1** to **21**-*n* may not be the same as one another.

The demultiplexer **24** demultiplexes a WDM optical signal received via a transmission line, and outputs optical signals corresponding to the optical receivers **23**-**1** to **23**-*n*. Each of the optical receivers **23**-**1** to **23**-*n* recovers a data string by demodulating corresponding optical signal.

FIGS. **3**A and **3**B illustrate examples of an optical transmitter that has a function to superimpose a supervisory signal. The optical transmitter illustrated in FIGS. **3**A and **3**B is an example of the optical transmitters **21**-**1** to **21**-*n* illustrated in FIG. **2**. However, the configuration of superimposing a supervisory signal on an optical signal with frequency modulation is not limited to the configuration or the method illustrated FIG. **3**A or FIG. **3**B.

The optical transmitter illustrated in FIG. **3**A includes a frequency tunable laser light source **31** and an optical modulator **32**. The frequency tunable laser light source **31** generates continuous wave light having an oscillation frequency corresponding to a frequency control signal. Therefore, when a supervisory signal is given as the frequency control signal, the frequency tunable laser light source **31** generates continuous wave light having the oscillation frequency corresponding to the supervisory signal. The optical modulator **32** modulates, with a transmission data stream, the continuous wave light generated by the frequency tunable laser light source **31**. As a result, the optical signal is generated with the supervisory signal superimposed by frequency modulation.

The optical transmitter illustrated in FIG. **3**B realizes the frequency modulation based on digital signal processing. That is, a mapping circuit **33** maps a transmission data stream to an I component data stream and a Q component data stream. An integration circuit **34** integrates the supervisory signal. Note that, in the configuration illustrated in FIG. **3**B, the supervisory signal f(t) is a digital data string representing an amplitude time waveform of a code or a tone signal. Further, the integration circuit **34** outputs, as an integration result, phase information θ(t) described below.

$$\theta(t)=\int 2\pi f(t)dt$$

A mod 2π circuit **35** converts the output value of the integration circuit **34** into a value within the range of 0 to 2π. However, when the integration circuit **34** is designed to have the output range of 0 to 2π, the mod 2π circuit **35** can be omitted.

A rotation operation circuit **36** rotates the I component data stream and the Q component data stream by the following operation using the phase information θ(*t*). Reference characters I and Q denote input data of the rotation operation circuit **36**. Further, reference characters I' and Q' are output data of the rotation operation circuit **36**.

$$I'=I\cos\theta(t)-Q\sin\theta(t)$$

$$Q'=I\sin\theta(t)+Q\cos\theta(t)$$

The data I' and the data Q', which are obtained by the rotation operation circuit **36**, are respectively converted into analog signals by D/A converters **37**, and given to an optical modulator **38**. The optical modulator **38** generates a modulated optical signal by modulating, with the data I' and the data Q', the continuous wave light outputted from a laser light source **39**. As a result, an optical signal is generated with the supervisory signal superimposed by frequency modulation.

FIG. **4** is a view for illustrating frequency modulation. FIG. **4** illustrates time-resolved output spectra of the optical transmitter at time points of T**0**, T**1** to T**4**. The spread of the output optical spectrum at each of the time points represents a spread of spectrum caused by the modulation based on the transmission data stream, and can take various widths and shapes according to the modulation scheme and modulation rate of the main optical signal. As described with reference to FIGS. **3**A and **3**B, a supervisory signal is superimposed by frequency modulation on an optical signal outputted from the optical transmitter. In the example illustrated in FIG. **4**, the supervisory signal is a digital code. The code superimposed on the optical signal at the time points of T**1** to T**4** is "0110". Further, the center frequency of the carrier light used by the optical transmitter is fc.

At time point T**0**, no supervisory signal is superimposed on the optical signal. In this case, the optical transmitter does not shift the center frequency of the optical signal. Therefore, the center frequency of the spectrum of the optical signal outputted at time point T**0** is fc.

At time point T**1**, "0" is superimposed on the optical signal. In this case, in this example, the optical transmitter shifts the frequency of the optical signal by −Δf. Therefore, the center frequency of the spectrum of the optical signal outputted at time point T**1** is fc−Δf.

At time point T**2**, "1" is superimposed on the optical signal. In this case, in this example, the optical transmitter shifts the frequency of the optical signal by +Δf. Therefore, the center frequency of the spectrum of the optical signal outputted at time point T**2** is fc+Δf. Similarly, the center frequency of the spectrum of the optical signal outputted at time point T**3** is fc+Δf, and the center frequency of the spectrum of the optical signal outputted at time point T**4** is fc−Δf.

The frequency shift Δf is sufficiently small as compared with the frequency of carrier light. Further, Δf is determined so as not to interfere with the adjacent channel of the WDM transmission system. For example, in the WDM transmission system in which wavelength channels are arranged on a 50 GHz/100 GHz frequency grid specified by ITU-T, Δf is not limited in particular but is set to about 1 MHz to 1 GHz.

In the example illustrated in FIG. **4**, the frequency shift, at the time when the supervisory signal is "0" or "1", is respectively set to "−Δf" or "+Δf", but the present invention is not limited to this method. For example, the frequency shift, at the time when the supervisory signal is "0" or "1", may respectively be set to "+Δf" or "−Δf". Further, it may also be configured such that, when the supervisory signal is "0" (or "1"), the frequency shift is set to 0, and such that, when the supervisory signal is "1" (or "0"), the optical frequency is shifted. Further, a supervisory signal may be superimposed on an optical signal by using multi-level frequency shift keying other than binary frequency shift keying.

Note that, although the supervisory signal is a digital signal in the example illustrated in FIG. **4**, the method for shifting the optical frequency is also substantially the same as the method used in the case where the supervisory signal is an analog signal. However, when the supervisory signal is an analog signal, the amount of the frequency shift is not discretely changed but is continuously changed.

FIGS. **5**A and **5**B are views for illustrating detection of a frequency modulated signal. Here, an optical signal carries a data signal and a supervisory signal. As described above, the supervisory signal is superimposed (or multiplexed) on the optical signal with frequency modulation. That is, the supervisory signal is an example of a frequency modulated signal (or FSK signal). Therefore, in the following description, a supervisory signal may be referred to as an "FSK-SV signal". Note that the center wavelength of this optical signal is λc.

For example, as illustrated in FIG. **5**A, a circuit, that detects an FSK-SV signal from the above-described optical signal, includes an optical filter **41**, a photo detector **42**, a DC-removal capacitor **43**, and a detector **44**. Further, an input optical signal is guided to the optical filter **41**.

As described above, the FSK-SV signal is multiplexed into the input optical signal with frequency modulation. For this reason, as illustrated in FIG. **5**B, the center wavelength of the optical signal is changed in the range between λc−Δλ and λc+Δλ according to the FSK-SV signal. FIG. **5**B illustrates spectra of the optical signal, and the transmission band (or pass band) of the optical filter **41**.

The photo detector **42** converts the light outputted from the optical filter **41** (that is, the optical signal filtered by the optical filter **41**) into an electrical signal. The electrical signal represents the power of the light outputted from the optical filter **41**. Here, the power of the light outputted from the optical filter **41** is represented by the area of the hatched region illustrated in FIG. **5**B. That is, when the center wavelength of the optical signal is λc−Δλ, the power of the light outputted from the optical filter **41** is expressed as P**1**, while when the center wavelength of the optical signal is λc+Δλ, the power of the light outputted from the optical filter **41** is expressed as P**2**.

The DC-removal capacitor **43** removes DC component from the electrical signal generated by the photo detector **42**. Therefore, the electrical signal outputted from the DC-removal capacitor **43** represents the FSK-SV signal converted into an amplitude component. Note that the data signal is assumed to be averaged, for example, by (high frequency band side) electrical band limitation of the photo detector **42** or by a low pass filter (not illustrated). Alternatively, when the operation speed of the photo detector **42** is sufficiently low as compared with the symbol rate of the data signal, the data signal is averaged by the photo detector **42**. The averaged data signal is substantially removed by the DC-removal capacitor **43**. The detector **44** detects the FSK-SV signal from the output signal of the DC-removal capacitor **43**.

However, the input optical signal includes AM noise. The AM noise is added to the optical signal, for example, in the transmission line between the optical transmitter and the optical receiver. Therefore, the signal P inputted to the detector **44** is expressed by the following expression. Note that 2×Psv represents an amplitude component resulting from the FSK-SV signal. 2×Pam_noise represents AM noise. Note that, each of the amplitude component and the AM noise is expressed by being multiplied by 2 for consistency with the following description.

$$P=2\times(Psv+Pam\_noise)$$

The detector **44** detects the FSK-SV signal by detecting 2×Psv from the signal P. Therefore, when Pam_noise is small as compared with Psv, the detector **44** can detect the FSK-SV signal with sufficient accuracy.

The magnitude of Psv depends on the frequency variation range (Δf in the example illustrated in FIG. **4**) of the FSK-SV signal. However, when the frequency variation range of the FSK-SV signal is large, the quality (for example, error rate) of data carried by the optical signal may be deteriorated. For this reason, the frequency variation range of the FSK-SV signal is controlled to be small so as to prevent deterioration of the quality of data. Thus, it is difficult to increase the magnitude of Psv. That is, it is difficult to sufficiently increase the magnitude of Psv with respect to Pam_noise.

FIG. **6** illustrates simulation results about the power of the amplitude component of FSK-SV signal and the power of AM noise. The horizontal axis represents the difference (that is, offset frequency) between the center frequency of the optical signal and the center frequency of the transmission band of the optical filter **41**. The frequency variation range of the FSK-SV signal is 100 MHz. The modulation depth of the AM noise is 2 percent. The width of the transmission band of the optical filter **41** is 20 GHz.

According to the simulation, the amplitude component of the FSK-SV signal is smaller than the AM noise. For example, even when the offset frequency is controlled so as to maximize the amplitude component of the FSK-SV signal, the amplitude component of the FSK-SV signal is smaller by about 7 dB than the AM noise. Therefore, it is difficult that the detection circuit illustrated in FIG. **5**A detects the FSK-SV signal with sufficient sensitivity.

FIG. **7** is a block diagram illustrating a configuration example of an asymmetry interferometer-type FSK-SV signal demodulator as the frequency modulation signal demodulator according to one embodiment. The asymmetry interferometer-type FSK-SV signal demodulator illustrated in FIG. **7** illustratively includes an optical filter **51**, optical propagation paths **52**, **54**A, **54**B, **57**A, **57**B, and **61**, an optical splitter **53**, an optical phase adjustment unit **55**, an optical delay unit **56**, an optical combiner **58**, a monitor PD **59**, a control circuit **60**, a photoelectric converter **62**, and a signal converter **63**.

The optical filter **51** is, for example, a band pass filter (BPF), and illustratively has the pass band illustrated in FIG. **5**B. That is, the BPF **51** illustratively has the central wavelength of the pass band at a wavelength that is shifted to the side of a long wavelength (or may be shifted to the side of a short wavelength), rather than the central wavelength λc, and has a bandwidth through which one portion of the optical signal band (the spectrum) of a wavelength channel, in the input WDM optical-signal, passes. The bandwidth may be illustratively set to a band narrower than half of the optical signal band of the wavelength channel. Light that passes through the BPF **51** includes an intensity modulation signal component that is in proportion to the FSK-SV signal. Moreover, the output optical power of the BPF **51** is also indicated by an area of a slanted-line region illustrated in FIG. **5**B in the same manner as the optical filter **41** described above. That is, the output optical power of the BPF **51** is indicated with P**1** when the central wavelength of the optical signal is λc−Δλ and is indicated with P**2** when the central wavelength of the optical signal is λc+Δλ.

The optical propagation path **52** leads the optical signal that passes through the BPF **51**, to the optical splitter **53**. The optical signal that propagates along the optical propagation path **52** is the optical signal that includes an intensity modulation component and a frequency modulation component. Moreover, an optical fiber or an optical waveguide may be applied to the optical propagation path **52**. The same embodiment holds in other optical propagation paths **54**A, **54**B, **57**A, **57**B and **61**.

The optical splitter **53** splits the optical signal that is input from the optical propagation path **52**, into two and thus outputs two optical signals to the optical propagation paths **54**A and **54**B, respectively. The optical splitter **53** may be realized using an optical coupler with two inputs and two outputs. In this case, one input port of the optical coupler may be an empty port.

The optical propagation path **54**A leads one optical signal that is split in the optical splitter **53**, to the optical phase adjustment unit **55**. Furthermore, the optical propagation path **54**B leads the other optical signal that is split in the optical splitter **53**, to the optical delay unit **56**.

The optical phase adjustment unit **55** adjusts a phase of the optical signal that is input from the optical propagation path **54**A. The adjustment is monitored in the monitor PD **59** and is controlled by the control circuit **60** according to the output optical power of the optical combiner **58**. The control is described in detail below.

The optical delay unit **56** delays the optical signal that is input from the optical propagation path **54**B. A delay time is illustratively set to approximately one-tenth of an FSK-SV signal period. The optical delay unit **56** may be illustratively realized using an optical fiber delay line. For example, if the FSK-SV signal is equivalent to 1 MHz and a maximum frequency deviation is 100 MHz, when a linear frequency change is assumed with the optical fiber delay line being 20 m, a phase difference of approximately π/10 (refer to the upper portion of FIG. **8**) may occur at a frequency changing point of the FSK-SV signal.

The optical propagation paths **57**A and **57**B lead the optical signals that are output from the optical phase adjustment unit **55** and the optical delay unit **56**, respectively, to the optical combiner **58**.

The optical combiner **58** causes the optical signals that are input from the optical propagation paths **57**A and **57**B, to interfere with each other and thus output interference light to the optical propagation path **61**. One portion of the interference light is split and led to the monitor PD **59**. The optical combiner **58** may be realized using the optical coupler with two inputs and two outputs.

The optical splitter **53** described above, and the optical propagation paths **54**A, **54**B, **57**A, and **57**B, the optical phase adjustment unit **55**, the optical delay unit **56**, and the optical combiner **58** are one example of an asymmetry-type optical interferometer **50**.

The monitor PD **59** generates the electric signal according to the power of the optical signal that is input from the optical combiner **58**, and thus outputs the generated electric signal to the control circuit **60**.

The control circuit **60** controls an amount of phase adjustment by the optical phase adjustment unit **55** according to the power that is monitored in the monitor PD **59**. In a time portion (a changing point of an FSK-SV signal pulse) in which values of FSK-SV signal components of the optical signals that are input from the optical propagation paths **57**A and **57**B, respectively, into the optical combiner **58** are different from each other, the control is illustratively performed such that the light is output to the photoelectric converter **62**.

The optical propagation path **61** leads the light that is output from the optical combiner **58**, to the photoelectric converter **62**.

The photoelectric converter **62** converts the light that is input from the optical propagation path **61**, into the electric signal. The electric signal is the electrical signal that indicates the frequency changing point (rising and falling) of the FSK-

SV signal pulse, and has a signal speed two times that of the electric signal of the FSK-SV signal that is superimposed at the transmitting side.

The signal converter **63** reproduces pulse information on the FSK-SV signal that is superimposed at the transmitting side, from the electric signal that is input from the photoelectric converter **62** and which indicates the changing point of the FSK-SV signal pulse, and thus reproduces the FSK-SV signal.

In the asymmetry interferometer-type FSK-SV signal demodulator described above, first, the optical signal of one portion (a band narrower than half of the signal band) of the signal band of the wavelength is cut out from the input WDM optical-signal in the BPF **51**. The cut-out optical signal has the central wavelength in a wavelength that is shifted from the central wavelength of the optical signal of the wavelength to the side of a long wavelength (or to the side of a short wavelength).

Subsequently, the optical signal that is cut out by the BPF **51** (that passes through the BPF **51**) is input to the optical splitter **53** along the optical propagation path **52**. The optical splitter **53** splits the optical signal that has been input into two and outputs one to the optical phase adjustment unit **55** and outputs the other to the optical delay unit **56**.

The optical signal that is input into the optical delay unit **56** is illustratively delayed by approximately one-tenth of a signal period of the FSK-SV signal and thus is output to the optical combiner **58**. The optical signal that is input into the optical phase adjustment unit **55** is phase-adjusted as described above and then is output to the optical combiner **58**.

One example of the frequency change over time in each optical signal that is input into the optical combiner **58** is illustrated on the upper portion of FIG. **8**. One example of the change over time in the output optical power of the optical combiner **58** is illustrated on the lower portion of FIG. **8**. On the upper portion of FIG. **8**, a waveform indicated with a solid line is equivalent to a waveform of the optical signal on which the delaying is not performed by the optical delay unit **56**, and a waveform indicated with a dotted line is equivalent to a waveform of the optical signal on which the delaying is performed by the optical delay unit **56**. Each optical signal relatively has a phase difference of approximately $\pi/10$ due to the presence or absence of the delaying.

As illustrated in FIG. **8**, in the time portion (the changing point of the FSK-SV signal pulse) in which the values of FSK-SV signal components are different from each other, the optical combiner **58** outputs the light. In other words, the change in the optical power according to an average phase difference between the optical signal on which the delaying is performed by the optical delay unit **56** and the optical signal on which the delaying is not performed appears in the output of the optical combiner **58**. For example, at the timing when the difference in value between the FSK-SV signal components (frequency components) reaches the maximum, a peak of the output light pulse occurs.

The optical pulse that is output from the optical combiner **58** as described above is output to the photoelectric converter **62** along the optical propagation path **61** and is converted into the electrical signal in the photoelectric converter **62**. The electric signal indicates the frequency changing point of the FSK-SV signal pulse. The pulse information on the FSK-SV signal that is superimposed at the transmitting side is reproduced in the signal converter **63** and thus the FSK-SV signal is reproduced.

FIG. **9** shows a waveform example (on the lower portion) of a transmission FSK-SV signal (the electric signal) and a waveform example (on the upper portion) of the electric signal that indicates the frequency changing point of the FSK-SV signal pulse described above. FIG. **9** shows the waveform example that results when the bit rate of the transmitted FSK-SV signal is 1 Mb/s and a frequency variation is 100 MHz. As understood from the comparison of the waveforms on the lower and upper portions of FIG. **9**, a demodulation signal is obtained that has the peak in the frequency changing point (rising and falling) of the transmission FSK-SV signal pulse. As a comparative example, a waveform that is equivalent to that in FIG. **9** when the BPF **51** is not provided is illustrated in FIG. **10**. As illustrated in FIG. **10**, the pulse is output at the frequency changing point (rising and falling) of the transmission FSK-SV signal pulse, but because the pulse has much noise, the FSK-SV signal is difficult to reproduce with high precision.

FIG. **11** shows an output waveform example of the photoelectric converter **62** that results when the pass band of the BPF **51** is set to 20 GHz and the offset frequency is set to 10 GHz. The horizontal axis of FIG. **11** indicates frequency, and the vertical axis indicates power. As shown in FIG. **11**, a second harmonic wave of the FSK-SV signal is greater by 20 dB than the AM noise (a modulation factor of 2%). That is, from the comparison with the example in FIG. **6**, it is apparent that a ratio of FSK-SV signal power and AM noise power (an SN ratio) is improved by approximately 30 dB.

FIGS. **12**A and **12**B are diagrams, each illustrating a difference between an amount of light that may be used in an FSK-SV signal demodulator according to the present embodiment and an amount of light that may be used in an FSK-SV signal demodulator in the related art. As illustrated in FIG. **12**B, in the FSK-SV signal demodulator in the related art, the amount of the change in the optical power that may be demodulated as the FSK-SV signal is (a portion indicated with the hatched region)×T (T=SV signal period), and an amount of light that may be used within one SV signal period is invariable and the amount of light itself is small. In contrast, as illustrated in FIG. **12**A, in the FSK-SV signal demodulator according to the present embodiment, the amount of the change in the optical power that may be demodulated as the FSK-SV signal is (a portion indicated with the hatched region)×Tp (Tp=a width of the pulse signal that occurs within the Tp=SV signal period). Moreover, a relationship between Tp and T is Tp<T/10. That is, in the FSK-SV signal demodulator according to the present embodiment, although in the pulse operation, a total amount of light that shortly passes through the optical filter **51** may be used. For this reason, because the optical output at the times other than the pulse output time is almost zero, the signal with an instantaneous value greater than that of the FSK-SV signal demodulator in the related art may be obtained. Therefore, effects such as the AM noise may be further reduced.

Optical Phase Adjustment Control by Control Circuit **60**

Next, one example of control of the optical phase adjustment unit **55** by the control circuit **60** is described. When briefly described, the control circuit **60** controls the optical phase adjustment unit **55** such that the average output power of the monitor PD **59** reaches the maximum, and thus it is possible to maximize the SN ratio of the optical signal that is output from the optical combiner **58**.

In the optical interferometer **50** illustrated in FIG. **7**, when the phase difference between the optical signals that pass through the two optical paths that run from the optical splitter **53** to the optical combiner **58** is an integer multiple of 2π, all light is output to the port (hereinafter referred to as a “monitor port”) that is connected to the monitor PD **59** of the optical combiner **58**. In contrast, when the phase difference between the two optical signals is not an integer multiple of 2π, the optical component is output to the port to which the photoelectric converter **62** of the optical combiner **58** is connected. Therefore, the following 4 cases are considered.

(1) There is a case where the phase difference between the two optical paths of the optical interferometer **50** is an integer multiple of 2π and the frequencies of the two optical signals that converge at the optical combiner **58** are the same. In this case, the light is output to the monitor port of the optical combiner **58**.

(2) There is a case where the phase difference between the two optical paths of the optical interferometer **50** is an integer multiple of 2π and the frequencies of the two optical signals that converge at the optical combiner **58** are different from each other. In this case, the light is output to the port to which the photoelectric converter **62** of the optical combiner **58** is connected.

(3) There is a case where the phase difference between the two optical paths of the optical interferometer **50** is not an integer multiple of 2π and the frequencies of the two optical signals that converge at the optical combiner **58** are the same. In this case, the light is output to each of the monitor port of the optical combiner **58** and the port to which the photoelectric converter **62** is connected.

(4) There is a case where the phase difference between the two optical paths of the optical interferometer **50** is not an integer multiple of 2π and the frequencies of the two optical signals that converge at the optical combiner **58** are different from each other. In this case, the light is output to each of the monitor port of the optical combiner **58** and the port to which the photoelectric converter **62** is connected.

That is, if the phase difference between the two optical paths of the optical interferometer **50** is not an integer multiple of 2π, regardless of the presence or absence of the frequency difference between the two optical signals that converge at the optical combiner **58**, the light is output to both the monitor port of the optical combiner **58** and the port to which the photoelectric converter **62** is connected. For this reason, the SN of the optical signal demodulation at the frequency changing point deteriorates. In order to avoid the deterioration, for example, a phase condition for the two optical signals that converge at the optical combiner **58** is adjusted by the optical phase adjustment unit **55**.

The optical phase adjustment unit **55** adjusts a phase of light with a medium (an optical waveguide, an optical fiber, or the like) along which the optical signal may propagate by changing a refractive index of the medium. If the refractive index of the medium is adjusted with a change in temperature, this may be done by changing temperatures of the optical waveguide and the optical fiber with an approaching heater, a Peltier element, or the like. Furthermore, when the optical waveguide is configured from a material that has an electrooptic effect, the phase of light may be adjusted by changing a voltage that is applied.

Furthermore, an optimal value of the delay time that is given to one optical signal by the optical delay unit **56** is determined by a modulation period T of the FSK-SV signal and rising time and falling time (tr/tf) of the frequency modulation of the optical signal. In such an optimal state (when the optical signal with the satisfactory SN ratio is output to the port to the photoelectric converter **62** of the optical combiner **58**), the SN ratio of the optical signal reaches the maximum. For this reason, if the rising/falling time (tr/tf) of the frequency modulation of the optical signal is significantly small with respect to a frequency modulation period T, that is, if (tr+tf)<<T, because the power of the optical signal that is input into the optical interferometer **50** is almost invariable over time, the output of the monitor port comes close to approximately (T−(tr+tf))/T×(the input port to the optical interferometer **50**) and thus the output reaches the maximum.

For example, when simulation calculation is performed, assuming that the bit rate of the FSK-SV signal is 1 Mb/S and a modulation period of the FSK-SV signal is 1,000 ns, as shown in FIG. **13**, the SN ratio of the optical signal to be obtained becomes best if the delay time is set to 130 ns. At this time, average output of the monitor port of the optical combiner **58** reaches the maximum. Moreover, the optimal delay time changes according to the bit rate of the FSK-SV signal. For this reason, in the control circuit **60**, the SN ratio of the optical signal to be obtained may be obtained to be the maximum by controlling the optical phase adjustment unit **55** such that the average output of the monitor port of the optical combiner **58** reaches the maximum.

Furthermore, as shown in FIG. **14**, in the optical interferometer **50** illustrated in FIG. **7**, if the optical signals that pass through the two optical paths are an integer multiple of 2π, the SN ratio of the optical signal to be obtained becomes best and at this time, the average output of the monitor port of the optical combiner **58** reaches the maximum. Therefore, in the control circuit **60**, the SN ratio of the optical signal to be obtained may be obtained to be the maximum by controlling the optical phase adjustment unit **55** such that the average output of the monitor port reaches the maximum.

FIRST MODIFICATION EXAMPLE

FIG. **15** is a block diagram illustrating a configuration example of an asymmetry interferometer-type FSK-SV signal demodulator according to a first modification example of the embodiment described above. The asymmetry interferometer-type FSK-SV signal demodulator illustrated in FIG. **15** is a polarization diversity configuration equivalent of the configuration illustrated in FIG. **7**. That is, the signal demodulator illustrated in FIG. **15** includes a polarization separation element **64** at the rear portion of the BPF **51**, and the polarization separation element **64** separates light that passes through the BPF **51**, into two mutually orthogonal polarization components, and performs signal processing corresponding to a block indicated with a dotted line A in FIG. **7**, on each polarization component.

The polarization separation element **64** may illustratively be realized using a polarization beam splitter or the like that uses a birefringent crystal or a multilayer coated prism. One polarization wave component (for example, a polarization wave component in which a direction of electric field vibration is the upper and lower direction with respect to a sheet of paper on which FIG. **15** is drawn) that results from the separation in the polarization separation element **64** is led to an optical splitter **53**A through an optical propagation path **65**A. The other polarization wave component (for example, a polarization wave component in which the direction of electric field vibration is the vertical direction with respect to the sheet of paper on which FIG. **15** is drawn) that results from the separation in the polarization separation element **64** is led to an optical splitter **53**B through an optical propagation path **65**B.

Each of the optical splitters **53**A and **53**B is the same as or similar to the optical splitter **53** illustrated in FIG. **7**, and causes one polarization component that results from the separation in the polarization separation element **64**, to split into two. One polarization component that is split into two in the optical splitter **53**A is input, through optical propagation paths **54**A and **54**B, into an optical phase adjustment unit **55**A and an optical delay unit **56**A that correspond to the one polarization component.

The optical phase adjustment unit **55**A and the optical delay unit **56**A are the same as or similar to the optical phase adjustment unit **55** and the optical delay unit **56** illustrated in FIG. **7**, respectively. Therefore, the optical phase adjustment unit **55**A and the optical delay unit **56**A give a relative phase difference as described above to the two optical signals that result from splitting one polarization component in the optical splitter **53**A. The phase difference, as described above, is controlled (adjusted) by the control circuit **60**A such that the average output power of a monitor PD **59**A reaches the maximum.

The output light of the optical phase adjustment unit **55**A and the output light of the optical delay unit **56**A are input into an optical combiner **58**A through corresponding optical propagation paths **57**A and **57**B, respectively. The optical combiner **58**A is the same as or similar to the optical combiner **58** described in FIG. **7**. Therefore, with respect to one polarization component, the optical combiner **58**A outputs the optical pulse according to the frequency changing point of the FSK-SV signal, as illustrated in FIGS. **8** and **9**. The optical pulse is led to a photoelectric converter **62**A through an optical propagation path **61**A.

The photoelectric converter **62**A is the same as or similar to the photoelectric converter **62** illustrated in FIG. **7**. Therefore, with respect to one polarization component, the photoelectric converter **62**A converts the optical pulse that is output from the optical combiner **58**A, into the electric signal and thus obtains the electric signal that indicates the frequency changing point of the FSK-SV signal pulse.

On the other hand, one polarization component light that is split into two in the optical splitter **53**B is input, through optical propagation paths **54**A and **54**B, into an optical phase adjustment unit **55**B and an optical delay unit **56**B that correspond to the other polarization component.

The optical phase adjustment unit **55**B and the optical delay unit **56**B are the same as or similar to the optical phase adjustment unit **55** and the optical delay unit **56** illustrated in FIG. **7**, respectively. Therefore, the optical phase adjustment unit **55**B and the optical delay unit **56**B give a relative phase difference as described above to the two optical signals that result from splitting the other polarization component in the optical splitter **53**B. The phase difference, as described above, is controlled (adjusted) by the control circuit **60**B such that the average output power of a monitor PD **59**B reaches the maximum.

The output light of the optical phase adjustment unit **55**B and the output light of the optical delay unit **56**B are input into an optical combiner **58**B through the corresponding optical propagation paths **57**A and **57**B, respectively. The optical combiner **58**B is the same as or similar to the optical combiner **58** described in FIG. **7**. Therefore, with respect to the other polarization component, the optical combiner **58**B outputs the optical pulse according to the frequency changing point of the FSK-SV signal as illustrated in FIGS. **8** and **9**. The optical pulse is led to a photoelectric converter **62**B through an optical propagation path **61**B.

The photoelectric converter **62**B is the same as or similar to the photoelectric converter **62** illustrated in FIG. **7**. Therefore, with respect to the other polarization component, the photoelectric converter **62**B converts the optical pulse that is output from the optical combiner **58**B, into the electric signal and thus obtains the electric signal that indicates the frequency changing point of the FSK-SV signal pulse.

The electric signals that are obtained in the photoelectric converters **62**A and **62**B according to the polarization component, respectively, converge in an electric signal combiner **66** in terms of electric current and are input into the signal converter **63**. The signal converter **63** is the same as or similar to the signal converter **63** illustrated in FIG. **7**, and reproduces the pulse information on the FSK-SV signal that is superimposed at the transmitting side, from the electric signal that indicates the frequency changing point of the FSK-SV signal pulse and thus reproduces the FSK-SV signal.

As described above, because the asymmetry interferometer-type FSK-SV signal demodulator that has a polarization diversity configuration performs the same signal processing on each of the polarization components that result from the separation in the polarization separation element **64**, at least an optical component portion performs dual system processing.

Furthermore, an optical system, for example, a polarization maintaining optical-fiber, or the like, which maintains a polarization state of the corresponding polarization component may be used for the optical propagation paths between the polarization separation element **64** and the photoelectric converters **62**A and **62**B. Additionally, control by the dual system optical interferometer may be individual control, except for making the polarization components equal in an amount of optical delay to each other. However, the control (by the control circuits **60**A and **60**B) may be common to each of the polarization components.

Because the optical signal processing is caused to be performed on each of the polarization components by setting the FSK-SV signal demodulator to have the polarization diversity configuration, a change in an interference state of light due to a change in a polarization state within an optical unit (within the optical propagation path), which occurs in a case of a common configuration that is not the polarization diversity configuration, is suppressed. Therefore, more stability is secured than in the case of the common configuration and thus the FSK-SV signal may be received.

SECOND MODIFICATION EXAMPLE

FIG. **16** is a block diagram illustrating a configuration example of an asymmetry interferometer-type FSK-SV signal demodulator according to a second modification example of the embodiment described above. When compared with the configuration illustrated in FIG. **7**, the asymmetry interferometer-type FSK-SV signal demodulator illustrated in FIG. **16** is different in that an etalon-type optical filter **51**A is provided instead of the optical filter **51**.

The etalon-type optical filter **51**A, as illustrated in FIG. **17**, has a pass band that changes periodically with respect to a wavelength. Moreover, a spectrum of each channel of the WDM signal is illustrated in FIG. **17**. The spectrum of each of channels (i−1), i, (i+1) is doubly depicted with solid and dashed lines and this indicates an aspect in which the spectrum changes due to the FSK-SV signal.

Each channel for the input WDM signal is illustratively arranged at an invariable or almost invariable wavelength interval. As one nonrestrictive example, the channel is arranged at an interval of 50 GHz. Then, the FSK-SV signals are multiplexed on the optical signal on each channel.

The etalon-type optical filter **51**A, as illustrated in FIG. **17**, has the pass band at the interval of $\Delta\lambda 1$. Moreover, $\Delta\lambda 1$ is almost the same as the interval at which each channel for the input WDM signal is arranged.

The etalon-type optical filter **51**A, illustrated in FIG. **17**, is controlled such that the pass band is arranged that corresponds to the long wavelength side (or may correspond to the short wavelength side) of the central wavelength of the spectrum of each channel for the WDM signal. If the etalon-type optical filter **51**A is controlled as illustrated above, a component that is extracted from each channel for the WDM signal is substantially the same as in the embodiment illustrated in FIGS. **7** and **8**.

Therefore, in the photoelectric converter **62**, a signal is obtained that is equivalent to a signal that results from combining the electric signals indicating the frequency changing points of the FSK-SV signals (P_{sv_i}) that are included in the input WDM signal and which are superimposed onto each channel (i). Therefore, the FSK-SV signal may be demodulated, with high precision, from the optical signal in the input WDM signal.

FIG. **18** is a block diagram illustrating a configuration example of a differential encoder according to the second modification example. The differential encoder illustrated in FIG. **18** is possible to apply to the optical transmitter illustrated in FIGS. **2** and **3**. For example, a signal b_n that is differential-encoded by the differential encoder illustrated in FIG. **18** may be used as the "supervisory signal" in the optical transmitter illustrated in FIGS. **3**A and **3**B.

The differential encoder illustratively includes a delay element **67** that outputs a delay signal a_{n-1} by delaying an input signal a_n, and an EX-OR circuit **68** that outputs a differential encoder signal b_n by performing an exclusive-or (EX-OR) operation on the input signal a_n and the delay signal a_{n-1}. Moreover, FIG. **19** illustrates a truth-value table of the differential encoder. The differential encoder generates and outputs a differential encode signal b_n according to the truth-value table.

FIG. **20** is a block diagram illustrating a configuration example of the signal converter **63** described above. An output (electric signal) of an optical receiving unit **69** of a front end unit is input into the signal converter **63**. The optical receiving unit **69** illustratively includes a preceding units of the signal converter **63** in the configuration illustrated in FIG. **7** or **15**, or includes the configuration illustrated in FIG. **16**.

At this point, the signal converter **63** may demodulate the FSK-SV signals that are multiplexed on the optical signal on each channel for the WDM signal.

In this example, the FSK-SV signal is realized with mutually orthogonal codes. Furthermore, the WDM signal is set to accommodate m wavelength channels. In this case, the signal converter **63** has a sampling device **71**, shift registers **72-1** to **72**-*m*, correlators **73-1** to **73**-*m*, and decision devices **74-1** to **74**-*m*. Moreover, if the input WDM signal is generated by the WDM transmission apparatus illustrated in FIG. **2**, preferably, a relationship between m and n is m=n.

The sampling device **71** samples a signal that is output from the optical receiving unit **69**. A frequency of a sampling clock, for example, is the same as a bit rate (or a chip rate) of a code indicating the FSK-SV signal. Then, a sample data stream that is obtained by the sampling device **71** is led to the shift registers **72-1** to **72**-*m*. Each length of the shift registers **72-1** to **72**-*m* is the same as a bit length of the code indicating the FSK-SV signal.

The correlators **73-1** to **73**-*m* are given corresponding codes 1 to m, respectively. The codes 1 to m, for example, are given by the NMS **10** illustrated in FIG. **1**. Furthermore, the codes 1 to m are codes that are expected to be multiplexed on the optical signal in the input WDM signal. Then, each of the correlators **73-1** to **73**-*m* calculates correlations between the codes 1 to m and the sample data streams that are retained in the shift registers **72-1** to **72**-*m*, respectively. Moreover, contents of each of the codes 1 to m is not fixed information, and indicates the number of the concurrent signal processing tasks in parallel that are performed by the signal converter **63**. Generally, a total number of pieces of code information that are managed by the NMS **10** illustrated in FIG. **1** is greater than m.

The decision devices **74-1** to **74**-*m* compare correlation values that are calculated by the correlators **73-1** to **73**-*m*, respectively, with a threshold. Then, the decision devices **74-1** to **74**-*m* determine whether the codes 1 to m are demodulated, based on a result of this comparison. For example, if the correlation value that is calculated by the correlator **73-1** is greater than the threshold, the decision device **74-1** extracts the FSK-SV signal from a channel 1 for the input WDM signal.

As described above, in one or more transmission sides, the FSK-SV signal on each channel, which is realized with the codes that intersect each other orthogonally and which is included in the WDM optical-signal, is made a differential signal and thus is transmitted. A transmission signal turns into the WDM optical-signal that results from the proper combination by the ROADM, and receives the FSK-SV signal on each channel, which is included in that WDM optical-signal, differentially received in the photodetector **69** and thus converts the differentially-received FSK-SV signal into the electric signal. In this state of the electric signal, the signal converter **63** may receive (in parallel perform receiving processing on) the electric signal, at the same time, that is restored to the mutually orthogonal codes.

Light Transmitting Apparatus

FIG. **21** illustrates one example of an optical transmission apparatus that includes a circuit (a signal demodulator) which demodulates the FSK-SV signal. The optical transmission apparatus illustrated in FIG. **21** is illustratively an ROADM **200**. The ROADM **200** has an optical amplifier **201**, an optical splitter **202**, a wavelength blocker **203**, an optical splitter **204**, an optical coupler **205**, an optical amplifier **206**, and a signal detection circuit **207**. The signal detection circuit **207** includes configurations illustrated in FIG. **7**, **15**, **16**, or **20**.

The optical amplifier **201** amplifies the input WDM signal. The optical splitter **202** leads the WDM signal amplified by the optical amplifier **201** to the wavelength blocker **203** and splits WDM signal and thus generates a drop signal. The drop signal, for example, is led to a wavelength selection device or a demultiplexer not illustrated. The wavelength selection device selects the designated wavelength from the drop signal and thus leads the selected designated wavelength to a client terminal. The demultiplexer demultiplexes the drop signal at every wavelength. In this case, some of, or all of the multiple optical signals that are obtained by the demultiplexer are led to the client terminal.

For example, according to an instruction from the network management system **10**, the wavelength blocker **203** allows the designated wavelength in the input WDM signal to pass through and blocks other wavelengths. The optical splitter **204** splits the optical signal that is output from the wavelength blocker **203**, and thus leads the split optical signals to the optical coupler **205** and the signal detection circuit **207**. The optical coupler **205** generates an output WDM signal by adding an add signal to the optical signal that is output from the optical splitter **204**. The add signal, for example, is transmitted from the client terminal. Then, the optical amplifier **206** amplifies the output WDM signal that is obtained by the optical coupler **205**. Moreover, the ROADM **200** may be configured to have a wavelength selection switch, instead of the wavelength blocker **203** illustrated in FIG. **21**.

Operation of the signal detection circuit **207** is as described referring to FIGS. **7** to **20**. That is, the signal detection circuit

207 demodulates the FSK-SV signals that are superimposed onto any channel for the WDM signal that is led from the optical splitter 204.

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A frequency modulation signal demodulator, comprising:

an optical signal that has a wavelength, a frequency modulation signal being superimposed onto the optical signal;

an optical filter that inputs the optical signal and has a central wavelength of a pass band at a wavelength that is shifted from a central wavelength of a spectrum of the optical signal and that is set to allow the pass band to be located at one portion of the spectrum; and

an asymmetry optical interferometer that demodulates the frequency modulation signal by splitting light which has passed through the optical filter, delaying different time between split lights, and interfering the split lights.

2. The frequency modulation signal demodulator according to claim **1**, further comprising:

a monitor that monitors output optical power of the optical interferometer; and

a control circuit that adjusts the delay difference such that a temporal average value of the output optical power monitored in the monitor reaches the maximum.

3. The frequency modulation signal demodulator according to claim **1**, further comprising:

a polarization separation element that separates the output light of the optical filter into different polarization components,

wherein the optical interferometer is respectively provided to the polarization components.

4. The frequency modulation signal demodulator according to claim **1**,

wherein the pass band of the optical filter is set to have a bandwidth narrower than half of the spectrum of the optical signal having the wavelength.

5. The frequency modulation signal demodulator according to claim **1**,

wherein the optical filter is an etalon-type optical filter.

6. The frequency modulation signal demodulator according to claim **1**,

wherein a relative phase difference is approximately $\pi/10$ in a frequency changing point of the optical signal of the delay interferometer.

7. A light receiving apparatus that receives an optical signal onto which a frequency modulation signal is superimposed, the light receiving apparatus comprising:

an optical filter that has a central wavelength of a pass band at a wavelength that is shifted from a central wavelength of a spectrum of an optical signal having a wavelength, a frequency modulation signal being superimposed onto the optical signal, and that is set to allow the pass band to be located at one portion of the spectrum; and

an asymmetry optical interferometer that demodulates the frequency modulation signal by splitting light which has passed through the optical filter, delaying different time between split lights, and interfering the split lights.

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